



Course: **ESD166J - Sustainable Energy**

Term Paper Title: **Shell Projects on Renewable Energy**

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OUTLINE

Shell Projects on Renewable Energy

1. Executive Summary
2. Introduction
3. Overview of two possible future scenarios and sources of energy
 - Sustained Growth scenario
 - Dematerialization scenario
4. Present projects working on
 - 4.1. Solar Home Systems in Rural Villages
 - 4.1.1. Description of the project
 - 4.1.2. Technology
 - 4.1.3. Social importance
 - 4.1.4. Economic issues
 - 4.1.5. Environmental issues
 - Kerosene Lighting
 - Battery Charging
 - Overall Direct CO₂ Displacement Potential
 - Non-GHG Environment Benefits
 - 4.2. Offshore Wind Turbines in United Kingdom
 - 4.2.1. Description of the project
 - 4.2.2. Technology
 - 4.2.3. Design and technical considerations
 - 4.2.4. Economic issues
 - 4.2.5. Environmental issues
 - Land Use
 - Visual Effects
 - Noise
 - Bird Deaths
5. Conclusion and future prospects of these technologies

1. Executive Summary

The current pace of growth in world energy demand is expected to lead to a substantial increase in aggregate commercial energy demand - under 2 per cent per year between 1995 and 2020. The potential consequences on climate change are profound, if the growth in energy demand is not met in a sustainable manner.

This implies that all actors - Governments, the international community, the private sector and non-governmental organizations - should pursue:

- (a) Efficiency in energy production, transmission, distribution and, in particular, energy end-use;
- (b) A shift towards energy sources and technologies with reduced environmental impact, including emissions of greenhouse gases; and
- (c) Promoting, developing and implementing policies and programmes, as appropriate, designed to ensure their adoption.

Under this projected scenario, the Royal Dutch / Shell Group of Companies (from here on, Shell) is planning to invest US\$500 million over the next 5 years to contribute to the development of renewable sources of energy, which will help to reduce the present impact of fossil fuels on climate change.

Solar Home Systems in Rural Villages

Among the many technologies proposed to address climate change, one stands out for its ability to generate emission-free power while improving rural lives: small solar electric systems can cost-effectively supply energy to rural parts of the developing world while substituting for energy sources that emit carbon dioxide (CO₂). These systems enable people in the countryside to fashion more comfortable lives amidst isolation and frequent poverty.

Photovoltaic (PV) solar home systems (SHS) are often the least expensive electrification option in sparsely populated areas with low electric loads. Typically consisting of a 10- to 50-watt peak (Wp) PV module, a rechargeable lead-acid battery, and some-times a

charge controller, the systems generate modest amounts of electricity for lights, radio, television, and other small appliances.

Each solar home system directly displaces a modest amount of greenhouse gas emissions by substituting for other energy sources in rural homes. Because of the very large number of homes still unelectrified and because SHS are often the least-cost electrification option, they potentially can play a significant role in GHG control. In addition to directly displacing fossil fuel consumption, the SHS market can help build the international PV industry, leading to lower production costs and increased PV sales for a range of applications with substantial climate change mitigation benefits.

Offshore Wind Turbines in UK

Offshore wind farm is the other technology that can positively impact on climate change. Actually several near-shore projects exist (Denmark, Sweden, Netherlands). True offshore projects (>5km off-shore, water depth <20m) provide better wind qualities and a vast increase in the exploitable resource (the availability of on-shore sites is limiting in N Europe).

The UK is one of the windiest countries in Europe and has enough offshore wind theoretically to supply three times the UK's current electricity requirements. UK companies have the potential to be fully involved in the manufacturing and installation of offshore wind farms. In a recent consultation document published by the Department of Trade and Industry (DTI), a potential for installing more than US\$ 4 billion of offshore wind farms around the UK was suggested.

Under this market conditions, two of the world's most powerful wind turbines are to be raised off the UK coast by a consortium, called Blyth Offshore Wind Limited, comprising Border Wind, PowerGen Renewables (a JV between Abbot Group and PowerGen), Nuon UK and Shell Renewables for the country's first offshore wind project.

The turbines, each of two Megawatt-capacity (enough in total to power 3,000 average households), will be the largest erected offshore in the world and the first to be built in such a demanding position, subject to the full forces of the North Sea.

Offshore wind farms have positive advantages with respect to onshore. Onshore designs will remain constrained by social and environmental factors, as much as by the practical need for (road) transportability of components, while offshore designs greatly reduce carry the social and environmental problems as noise, visual effects and land use.

2. Introduction

The main purpose of this paper is to provide a detailed analysis of two of the type of projects where Shell is placing some of the emphasis as part of the initiative to develop renewable sources of energy.

Before entering into these details, I am going to give an overview of the two scenarios that Shell considers the most possible ones for the future. Under these scenarios, different sources of energy are developed.

After this overview, I will mention some of the different projects under development related to renewable energy and focusing on the analysis of two important projects:

- Solar Home Systems in Rural Villages
- Offshore Wind Turbines in UK

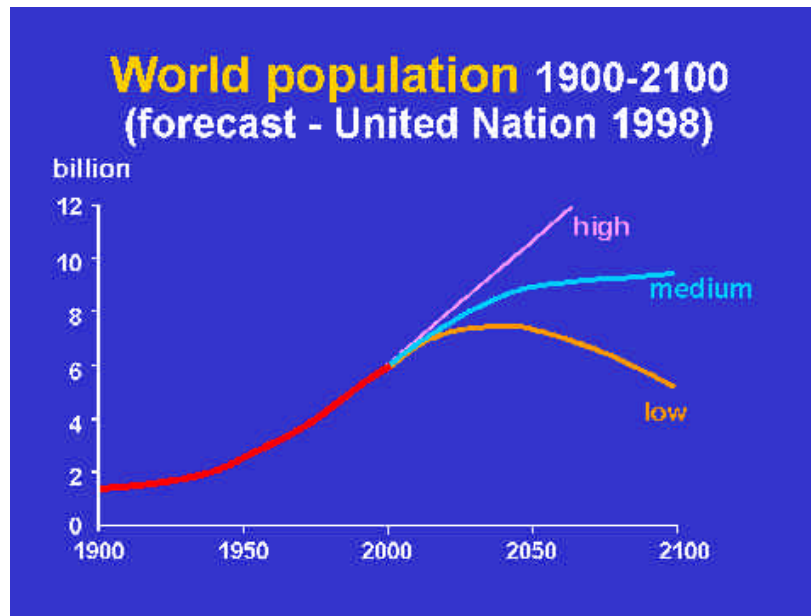
The analysis will be done with a description of the project and the technology, the social importance, the design and technical considerations and the economic and environmental issues of these technologies.

3. *Overview of two possible future scenarios and sources of energy*

Shell scenarios suggest energy needs could grow by 60% by 2020 - with demand increasing rapidly in developing countries, while it slows, or even declines, in developed ones. By 2020, developing countries should be consuming over half the world's energy.

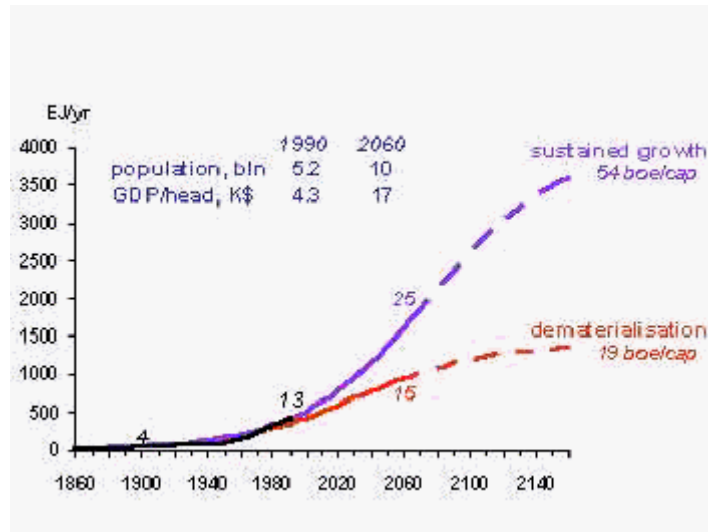
There are two scenarios that are predicted as possible outcomes in the future. In both scenarios, population growth follows "the World Bank base case" (see figure 1 with similar numbers from United Nations), gradually slowing down as economic development progresses. World population reaches 8.5 billion by 2030, and stabilizes at 10-12 billion by 2060.

Figure 1



For the world, energy per capita increased from 4 boe (barrels of oil equivalent) in 1900 to 13 boe currently. In the "Sustained Growth" scenario, this pattern would continue, reaching 25 boe by 2060, currently the Japanese level. In "Dematerialization", a different pattern emerges leading to 15 boe by 2060. Figure 2 shows a both scenarios.

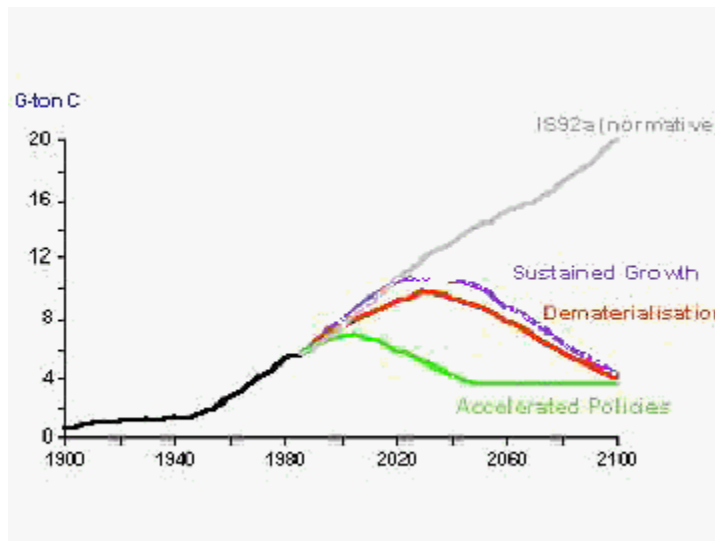
Figure 2



Two simple scenarios

CO₂ emissions from fossil fuels, as shown in figure 3, peak at around 10 G-tons C/year before the middle of the next century and decline to 4 G-tons C/year by 2100, leading to stabilization of CO₂ content in the atmosphere at about 550 - 600 ppm, according to current models, or 60% above current levels.

Figure 3



CO₂ Emission - Fossil Fuels

“Sustained Growth” scenario

Under the "Sustained Growth" scenario, companies and universities active in the deployment of renewable energy technologies would be successful, though they are stimulated by limited "pump priming" initiatives, such as subsidies. This would occur not only in OECD countries, but also in developing countries. As a result, the challenge of providing abundant energy at competitive prices would be met over the next decades.

New technologies steadily progress along their learning curves, first capturing niche markets, and by 2020 become fully competitive with conventional energy sources. Cost reductions reflect an 80% experience curve for solar photovoltaics and 85% for biomass. This is not unlike the progression of the oil industry 100 years ago (80%) and slower than that of electricity in the USA between 1926 and 1970, which followed a 75% experience curve (a 25% cost reduction for every doubling of cumulative production).

The cost of photovoltaic panels would be reduced, first by advanced automation in manufacturing and improved light conversion efficiency in current crystalline silicon technology. It could be followed by the large deployment of one or several types of thin film technologies.

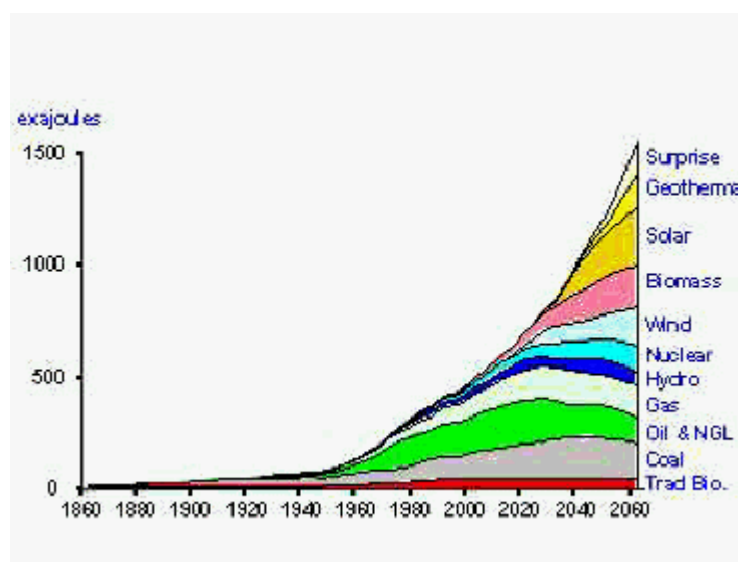
The cost of electricity from wind turbines will level out (they fell by 10% p.a. in real terms over the period 1980 - 1995). This occurred through improved reliability, optimization, design, location and economies of scale in manufacturing and stimulated by "pump priming" policies on certain governments. The emergence of an industry currently by a dozen major manufacturers will give it strength to take market share from other energy sources.

Renewable energy sources become significant by 2020

With primary energy growth at about 2%, supporting a 3% p.a. growth in GDP, "Sustained Growth" assumes an improvement in energy intensity of about 1% p.a. This was similar to the USA between 1880 and 1990, under free market conditions. Energy per capita continues its historical progression.

The use of fossil fuels increases steadily over the next 30 years, fuelling the economic development of a majority of the world population. By 2020-2030, they reach their maximum potential and no longer contribute to growth, being limited by the rate of production and commercialization of resources economically competitive with renewable energies. At that time, a number of developing countries (e.g. China and India), having reached a significant level of industrial development, increasingly turn their attention towards renewable energy sources.

Figure 4



"Sustained Growth" scenario

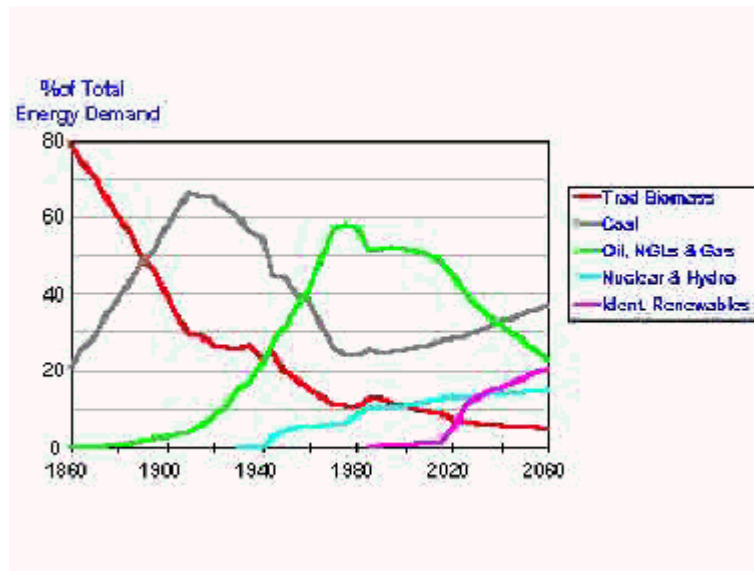
Having gradually become commercial over the next two decades, renewable energy technologies increase their market share as total energy demand grows. This allows growth in energy supplies to be sustained at a time when fossil fuels reach a plateau. It is not necessary, for this argument, to determine which renewable technology has the best prospects. Technologies will compete but the market will decide.

However, by 2060, sources of supply are likely to be more diversified than today. Perhaps ten different sources will each have a market share between 5 and 15%.

In this scenario, the rate of market penetration for identified renewable technologies - wind, biomass, and photovoltaic - is similar to that of coal or oil and gas in the past. A

second wave, possibly including magma energy and/or a surprise, might take-off by 2050. Figure 5 shows a breakdown of the forecasted shares of each source of energy.

Figure 5



Energy Market Share 1860-2060

“Dematerialization” scenario

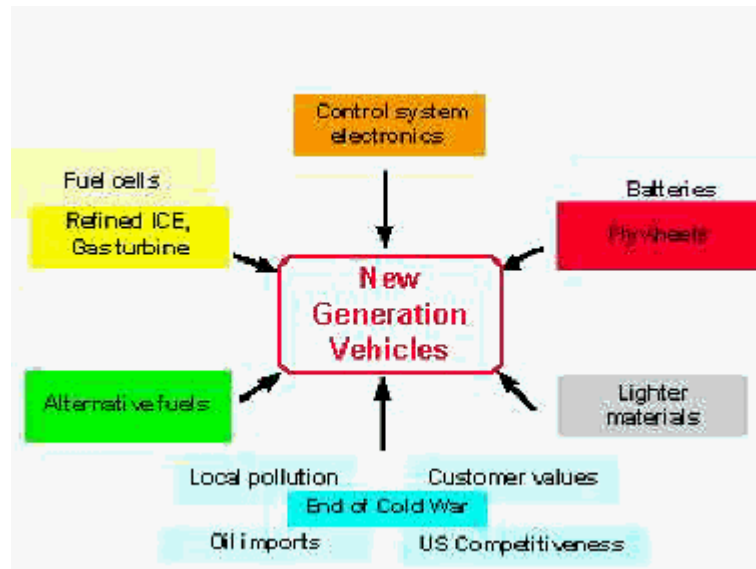
Human needs are met through technologies and systems requiring a much lower energy input. Under "Dematerialization", data highways and virtual reality, for instance, may be a precursor of a different lifestyle, a signal perhaps similar to the emergence of the automobile and individual mobility at the beginning of this century.

Thanks to advances in materials and design capabilities, objects and equipment will fulfill their function using ever less or lighter material. Carbon fibers are four times lighter than steel and yet twice as strong.

In road transport one could see a convergence of social and economic issues, new technologies - some of them developed for space application - alternative fuels and lighter materials. The result would be "New Generation Vehicles" (see figure 6), three times more fuel-efficient than today's vehicles. The challenge is to integrate these

technologies, lower their cost and develop a manufacturing infrastructure, probably along an evolutionary path.

Figure 6



Converging Developments

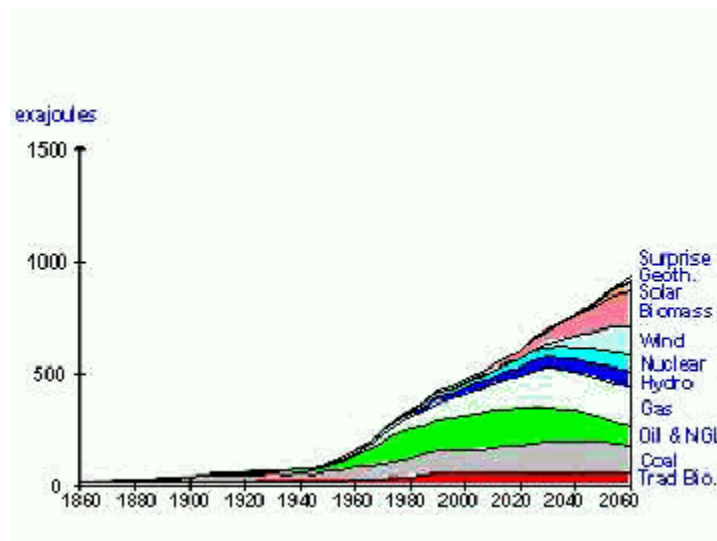
Energy consumption per capita remains virtually stable for the next 30 years

Improvements in energy intensity gradually reach a sustained 2% p.a. To support a 3% p.a. growth until 2030 in GDP, as developing economies expand. Thereafter, energy growth slows down to 1% p.a., as "Dematerialization" started in the more advanced regions of OECD countries, gradually spreads to industrializing and developing countries, once infrastructure has been built and GDP per capita is high enough. Countries restructuring their economies would improve their energy efficiencies drastically.

Coal and oil growth is lower in "Dematerialization" than in "Sustained Growth". However, more gas is being used to compensate for the delayed take-off on photovoltaic, postponed from 2020 to 2050. This technology remains a niche application until nanotechnology becomes widely applicable!

In "Dematerialization" (see figure 7), relentless advances in information technology, telecommunication, materials and biotechnology would enable high-energy intensity improvements to be sustained for several decades.

Figure 7



"Dematerialization" scenario

A different lifestyle possibly linked to changing individuals' and customers' behavior could emerge. Signs may already be perceivable such as virtual reality, but consequences are difficult to anticipate fully, perhaps similar to the scale of changes brought about by the automobile and individual mobility during the 20th century.

In "Dematerialization", the rate of market penetration for identified renewable energy - wind, biomass, and photovoltaic - is lower than in "Sustained Growth". The second wave for renewables is not needed until 2060.

Among many different possible paths along which the world energy system could develop, "Sustained Growth" and "Dematerialization" are two sustainable and plausible archetypes, which could happen through market mechanisms and with minimum stimulation.

4. Present projects working on

Shell companies are committed to developing commercial renewable energy. Recent developments include:

- Rural solar electrification projects in Bolivia (10,000 homes) and South Africa (50,000 homes)
- First commercial biomass scheme in Norway (acquisition of Kirkenær bark-fired district heating plant in early 1999, and building of a new briquette line, which will produce 10,000 ton per annum)
- Third Shell solar cell factory, in Germany (opened in November 1999, it is the world's most modern and Europe's largest solar cell plant)
- Blyth offshore wind project, in the UK, was announced at the end of 1999

In a number of different projects, Shell Hydrogen is developing various solutions to enable hydrogen-powered vehicles to reach the market. Shell Hydrogen and DBB Fuel Cell Engines GmbH, a subsidiary of Daimler Chrysler based in Germany, have recently demonstrated the viability of fuel cell vehicles running on gasoline. Shell contributes through the use of its proprietary world leading Catalytic Partial Oxidation (CPO) technology that has already been shown to successfully convert liquid fuels into hydrogen gas.

Shell Hydrogen is participating in a consortium to investigate the potential for creating the world's first hydrogen economy in Iceland. The first applications should be introduced between 2000 and 2002. One of the most likely applications to be introduced will be a hydrogen/fuel-cell powered bus service in Reykjavik.

Shell Hydrogen is also pursuing a viable hydrogen storage system, which will enable direct-hydrogen fuelled fuel cell vehicles to hit the road.

Another current project is the development of a solid oxide fuel cell system in partnership with Siemens Westinghouse, US. These power plants will be virtually free of emissions, because the resulting CO₂ can be sequestered, e.g. by re-injecting it into an empty well.

The next part for this paper is a deep analysis of two of the projects that Shell is working on.

4.1 Solar Home Systems in Rural Villages

4.1.1 Description of the project

This project that I chose to analyze is a commercial, solar-powered rural electrification scheme that is being set up in South Africa's Eastern Cape. It is the largest of its type ever attempted. It is expected to reach about 50,000 homes within three years.

The project is a joint venture between Eskom and Shell Renewables to deliver this service in South Africa. After just over a year since President Mandela opened the world's largest commercial Solar Rural Electrification project, Eskom-Shell Solar Home Systems (Pty) Ltd has sold a total of 6,000 contracts to people in rural South Africa. In January this year alone, a record 1,000 Solar Home System (SHS) contracts were sold.

There are approximately 8.6 million homes in South Africa. Of these, only 2.75 million (32%) had access to electricity in 1990. Today a massive electrification programme conducted mainly by Eskom has more than doubled the number, bringing electricity to 67% by the end of 1998. Despite this huge effort, it is unlikely that the grid will ever be extended to supply power to the smallest isolated rural communities.

4.1.2 Technology

The SHS is made up of a solar panel, a charge controlled battery and a security and metering unit. The Shell Solar manufacturing plant in Helmond, the Netherlands, supplies the solar panels. Typically consisting of a 10- to 50-watt peak (Wp) PV module, the systems generate modest amounts of electricity for lights, radio, television, and other small appliances.

The SHS and support infrastructure offers a viable solution in these locations. The "fee-for-service" concept is that customers pay approximately US\$ 30 to have the system

installed and approximately US\$ 8 every month for 30 days power. In return they receive a utility type service, including replacement of batteries and full maintenance. They used to spend about 8 dollars a month on kerosene and candles. Now they get access to clean power for the same amount.

It is this concept that makes the project unique, and provides people with the opportunity to install solar power without having to make a large up-front investment in equipment that they might not have been able to afford previously.

The other important issue that the unit tackles is security. Solar panels must by necessity be positioned outside buildings and are easily transported which has made theft a problem in some locations. This has been overcome by incorporating a patented SmartSwitch™ into the battery and the solar panel. These components will not function without the associated control system. The battery controller and pre-payment device are all housed in one enclosure, secure from unauthorized access.

If this project works commercially - in the long term - it holds tremendous potential. There are about one billion people in the world that could benefit from this technology.

4.1.3 Social importance

Roughly 2 billion people still lack grid electricity¹. Most are in rural areas of developing countries. The World Bank estimates that in 1990, electric grids served only 33% of rural developing-country homes. Achieving the vast increases in electrification needed to satisfy basic demand without significantly increasing global greenhouse gas (GHG) emissions would be a substantial challenge.

Estimates of the world's unelectrified population during the 1990s fell generally in the range of 1.8–2.0 billion people occupying 300–400 million homes, mostly in rural areas.

Table 1 presents an estimate of the unelectrified rural population in 1990 by region.

¹ World Bank, *Rural Energy and Development, Improving Energy Supplies for Two Billion People* (Washington, DC: World Bank, 1996)

TABLE 1: ESTIMATED UNELECTRIFIED RURAL POPULATION BY REGION, 1990

<i>Estimated Unelectrified Rural Population (million)</i>	
North Africa and the Middle East	73
Latin America and the Caribbean	75
Sub-Saharan Africa	314
South Asia	632
East Asia and the Pacific	642

Source: derived from World Bank electrification coefficients and population data.

Solar home systems have social, economic, and non-GHG environmental benefits. Vastly superior to kerosene lamps, electric lights enable families to extend their days after sunset productively and enjoyably, by studying, working, or simply cooking and eating dinner in a well lit home. Reducing the need to store and burn kerosene improves air quality and safety. The systems also ease access to information and entertainment via radio and television, and help families carry on income-generating activities.

4.1.4 Economic issues

Photovoltaic (PV) SHS are often the least expensive electrification option in sparsely populated areas with low electric loads. Market-oriented activities in a number of countries increasingly demonstrate the technology's technical and commercial viability². Based on consumers' ability to pay and experience with various system delivery and finance models, the SHS market could reach as many as 170 million off-grid rural homes, a 10% market penetration (Table 2).

Scenario	Number of People	Number of Homes	Installed PV Capacity	System Value in Dollars ^b
Lower-End Rural Market Potential (10% penetration)	170 million	34 million	1,360 megawatts	\$17 billion
Upper-End Rural Market Potential (50% penetration)	850 million	170 million	6,800 megawatts	\$85 billion

[^aAssumes an average system size of 40 Wp. ^bAssumes an average system cost of \$500 installed.]

² See, for example, Anil Cabraal, Mac Cosgrove-Davies, and Loretta Schaeffer, *Best Practices for Photovoltaic Household Electrification Programs*

On a life-cycle basis, the systems frequently cost about what rural households would otherwise spend on lighting fuels, dry cells, and car batteries. Yet the convenience and quality of service provided by an SHS generally far exceeds that of traditional alternatives. For example, one 15-watt fluorescent lamp or one 60-watt incandescent lamp provides the luminosity of 18 kerosene wick lamps or 60 candles³. Also, many households spend time, cash, and considerable effort transporting and charging car batteries so they can have access to television.

Given their cost and convenience advantages, it is not surprising that SHS are increasingly popular in many areas. While the price of an SHS can be made comparable with current household energy expenditures if systems are paid for over time, the high up-front cost is a substantial barrier to broader dissemination.

At current prices (ranging roughly from \$125 to \$1,300 for systems of 10 to 50 Wp), a small percentage of rural households can and will pay cash to purchase SHS, but many more will only acquire systems if given access to some form of financing. Consumer loans and “fee-for-service” arrangements, where households make periodic payments for the use of an SHS, can greatly increase affordability and market penetration.

Estimates of the potential SHS market in developing countries vary widely, depending on assumptions about the cost and availability of financing (see Table 2). The potential cash market is estimated as roughly 5–10% of the rural households currently without an electricity connection⁴. With access to loans and fee-for-service arrangements, however, the estimates suggest that the SHS market could reach up to 50% or more of unelectrified rural homes⁵.

³ R. Van der Plas and A.B. de Graaff, *A Comparison of Lamps for Domestic Lighting in Developing Countries*, Industry and Energy Department Working Paper, Energy Series Paper No. 6 (Washington, DC: World Bank, 1988)

⁴ For example, a report by the German development agency GTZ, evaluating its experience with SHS projects in 19 countries, estimated that “in most developing countries at least 10% of the rural households would be willing and able to pay cash for an SHS”; GTZ, *Basic Electrification for Rural Households* (Eschborn, Germany: 1996), p. 120.

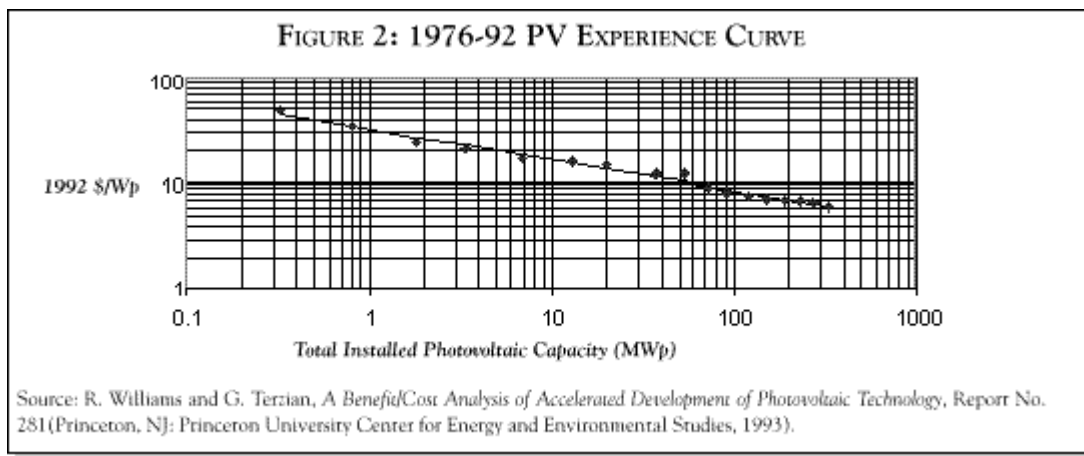
⁵ Soluz, Inc.’s market studies and commercial operations suggest fee-for-service arrangements could enable market penetrations of 50% or more in certain communities. Enersol Associates and Soluz Inc. are direct affiliates of Global Transition Consulting, two of the principals of which contributed to this report.

Based on rural consumers' ability-to-pay and the present cost for PV service, a 50% average penetration rate may be a reasonable upper-end estimate of the potential SHS market. Although a number of rural areas would probably not have this level of activity, others appear to have the potential for even higher levels of penetration on a commercial basis.

Another indirect though possibly substantial GHG benefit comes from the ability of SHS purchases to help fuel growth in the PV industry. If the SHS market can substantially increase PV module sales, this could help increase PV production capacity, bring down cell and module costs, and contribute to tremendous GHG benefits as PV's become cost-effective for a broader range of applications.

The relationship between cumulative production of a manufactured product and total cost per unit produced can be characterized by an experience curve. Empirical studies reveal a consistent pattern, generally attributable to the efficiency gains from learning-by-doing and economies of scale, whereby costs fall by an approximately fixed percentage with every doubling of cumulative production.

Figure 2 demonstrates the tight empirical relationship between cumulative industry-wide production and the unit price for photovoltaic.



This series from 1976 to 1992 indicates that inflation-adjusted prices drop by 18% with every doubling of cumulative production. Other analyses using different data sets and

periods have indicated price declines as high as 32%, but most studies indicate that prices have historically fallen by about 20% with every doubling of cumulative PV output⁶.

By extrapolating from the historical PV experience curve, it is possible to estimate future PV prices as a function of projected sales growth. If all current segments of the PV market grow by 20% annually and prices decline by 20% for every doubling of cumulative PV sales, module costs would fall from a 1998 whole-sale price of \$3.65 per Wp to about \$1.20 by 2018.

4.1.5 Environmental impact issues

Widespread SHS use could help developing countries onto a low-carbon path for rural electrification while providing an important market niche to help make PV's more competitive for a range of applications worldwide.

Kerosene Lighting Displacement

Most SHS projects structured for climate change mitigation anticipate that electric lights will displace nearly all kerosene lighting in homes, but the extent of actual kerosene displacement may vary. Where enough lights are installed and systems function properly, anecdotal reports suggest and at least one study confirms that kerosene displacement is nearly complete⁷. Studies of some SHS activities, however, report continued kerosene use in the 20–45% range⁸.

⁶ Richard Duke and Daniel M. Kammen, "The Economics of Energy Market Transformation Programs," *The Energy Journal*, vol. 20, no. 4 (1999), pp.15–64.

⁷ For example, the National Rural Electric Cooperatives Association's experience in Bolivia was cited in the USIJI application for an SHS project in that country to support the assumption of 100% kerosene displacement. In Honduras, household surveys conducted and documented in an unpublished 1999 study by Brown University student Maria Reff indicate 94% kerosene displacement for SHSs bought with cash and suggest higher levels of displacement for SHS rentals.

⁸ Continued kerosene use of 20% after SHS installations in Nepal from Regina Betz, *The Activities Implemented Jointly (AIJ) Project of the E7 Initiative: Renewable Energy Supply Systems in Indonesia: A Case Study*, ISI Working Paper (Karlsruhe, Germany: February 1999); continued kerosene use of 45% after an SHS project in India from Tata Energy Research Institute (TERI), *Evaluation of SPV Systems Installed Under INDO-US Collaboration Programme, Sundarbans, West Bengal* (draft) (Arlington, VA: 1998).

Battery Charging Displacement

In many developing countries, car batteries are commonly used to provide household electricity. Limited data suggest that perhaps 10% of all unelectrified households regularly charge lead-acid car batteries. In Kenya, for example, about 5% of the unelectrified homes charge lead-acid batteries (in addition to homes using SHS), while in Morocco 14% of rural homes use car batteries⁹. Recharging 50- to 100-amp-hour 12-volt batteries produces CO₂ emissions of roughly 15–30 kilograms a year for grid-based battery charging, and considerably more where small diesel and gasoline generators are used.

Overall Direct CO₂ Displacement Potential

The first 10% of SHS adopters are expected to be higher-income rural households who are motivated to gain better access to electricity. For this group, SHS are assumed to substitute for both kerosene lighting and battery charging, and baseline kerosene consumption is assumed to be relatively high, at 10 liters per month. Each SHS in this group directly displaces about 0.3 metric tons of CO₂ per year or about 6 tons over 20 years¹⁰.

SHS use for the next incremental 40% of potential adopters is assumed to displace kerosene alone, using 8 liters per month as the baseline. Each SHS for this group would displace about 0.2 tons of CO₂ per year on average or about 4 tons over 20 years.

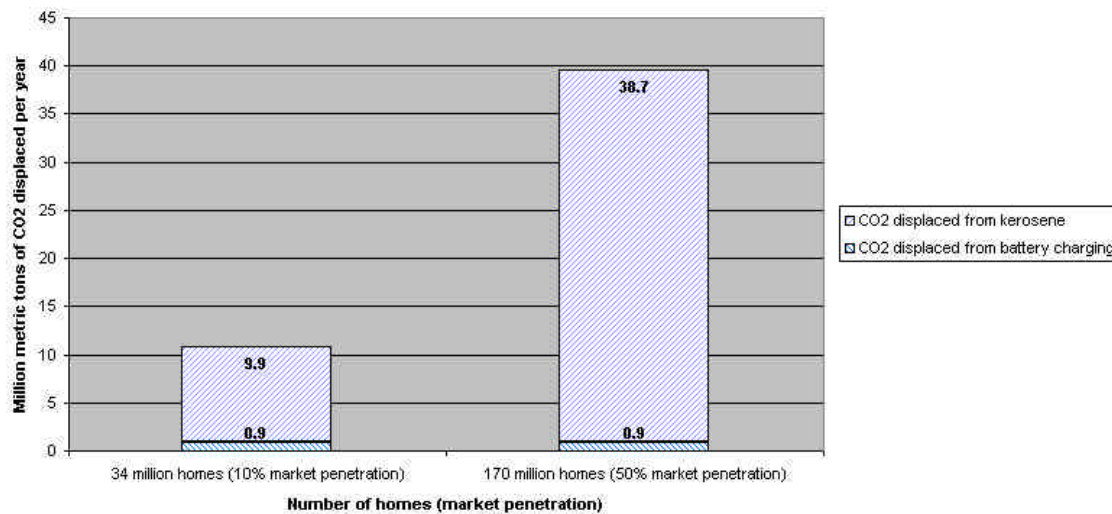
As illustrated in Figure 1, at 10% market penetration, SHS would directly displace roughly 10 million metric tons of CO₂ per year, while at 50% penetration the figure would be nearly 40 million tons. At the lower-end penetration level, the annual CO₂ emissions directly displaced would approximately equal CO₂ emissions from fossil fuel use in Zimbabwe during 1995, while at the upper-end level they would equal those of Switzerland for that year. Compared with the world's 23 billion tons of CO₂ emissions

⁹ M. Hankins, F. Ochieng, and J. Scherpenzeel, *PV Electrification in Rural Kenya: A Survey of 410 Solar Home Systems in 12 Districts*, Final Report, Prepared by Energy Alternatives Africa for the World Bank, ESMAP (November 1997); Michel Rodot and Abdelhanine Benallou, eds, *Electricite Solaire au Service du Developpement Rural* (Rabat: Reseau International d'Energie Solaire, 1993), p. 30.

¹⁰ Calculations assume that three battery charges per month result in 0.025 tons CO₂ emissions per year. In all cases, SHSs are assumed to displace 90% of baseline kerosene usage and each liter of avoided kerosene displaces 2.45 kg of CO₂.

from fossil fuel use in 1995, however, the amount of direct CO₂ displacement is still small¹¹.

Figure 1: Direct CO₂ Displacement from SHS Dissemination



Although the total direct CO₂ displacement per SHS is small, the rate, defined as CO₂ displacement per kilowatt-hour (kWh), is extremely high. Reports on AIJ and World Bank/GEF projects in Indonesia indicate that the rate of CO₂ displacement per kilowatt-hour (kWh) from SHS was 10 times greater than for renewable energy applications displacing fossil-fuel-based power generation. The high rate of displacement is due to the tremendous inefficiency of kerosene lighting.

Non-GHG Environmental Benefits

In addition to CO₂ displacement, decentralized photovoltaic systems offer other advantages like mitigating the risks and health problems associated with storing and using kerosene. In surveys conducted by India's Tata Energy Research Institute, people reported eye irritation, coughing, and nasal problems associated with the use of kerosene lamps¹². In addition to emitting pollutants with known respiratory impacts (such as carbon monoxide, nitrogen oxide, and hydrocarbons), kerosene lamps are a fire hazard.

¹¹ Country and world CO₂ emissions figures from World Resources Institute, *World Resources 1998–99* (New York: Oxford University Press, 1998), Tables 16.1 and 16.3.

¹² TERI - op. cit. footnote 8, Chapter 3, p. 7.

Solar electric systems often displace dry cell batteries that are used to power radios, cassette players, and flashlights. Since rural areas generally lack programs for solid waste management, the incineration or disposal of used dry cells in open dumps or as litter can contaminate soil and water sources with toxins, including mercury.

A negative environmental impact from SHS dissemination can result from the improper disposal of lead-acid batteries. While careful recycling of lead-acid batteries is the best way to prevent this, current recycling practices vary substantially by country. As SHS become widespread, it will be important to encourage well-managed battery recycling programs. In the near term, however, SHS dissemination may actually result in a net reduction in the rate of battery disposal.

4.2 Offshore Wind Turbines in UK

4.2.1 Description of the project

Two of the world's most powerful wind turbines are to be raised off the UK coast by a consortium, called Blyth Offshore Wind Limited, comprising Border Wind, PowerGen Renewables, Nuon UK and Shell Renewables, for the country's first offshore wind project.

The turbines, each of 2 Megawatt-capacity (enough in total to power 3,000 average households), will be the largest erected offshore in the world and the first to be built in such a demanding position.

Blyth Offshore wind farm will be built during the middle of this year 2000. The turbines will be manufactured by a Danish wind energy company, Vestas, and installed by the marine division of AMEC Capital Projects and Seacore.

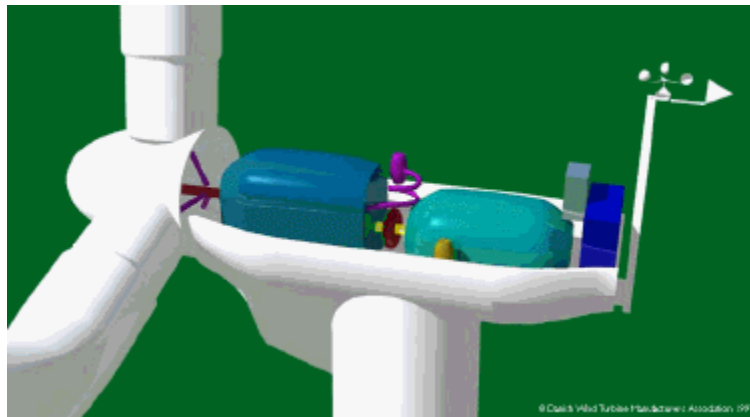
The two wind turbines will be erected one kilometer off the coast Northumberland, close to the existing Blyth Harbour wind farm (see picture below) in an average water depth of eight meters.



Existing Blyth Harbour wind farm

4.2.2 Technology

The typical design of modern wind turbines has evolved since the 1970s, from mainly Danish origins. The visual aspect is a tall, slender tower, supporting a nacelle with a propeller-like, three-bladed rotor on a horizontal axis (see image below). The nacelle contains all the rotating parts, and allows access for maintenance and inspection. Electronic control equipment sits in the tower base. A comprehensive supervisory control and data acquisition system with remote operation is becoming standard. Also standard is a twenty-year life span, although many turbines are designed to last for longer.



Diagrammatic view of a wind turbine nacelle

Key components in a typical generating system	
Wind	Between 5 and 25m/s (Beaufort force 4 - 9)
Rotor blades	Traditional composites, such as glass-reinforced plastic or wood-epoxy
Rotor	Usually constant rotation speed in the range 20-35rpm for 1.5-0.5MW machines
Gearbox Speed	Up to 1500rpm
Induction generator	50Hz, 690V
Power control system	Match to grid operator requirements
Transformer	33kV
Grid connection	Sub-station with metering equipment

4.2.3 Design and technical considerations

The Blyth project was reassessed in 1998 to make sure it was still relevant to future developments. As a result the turbine size has been increased from the original 750 kW to 2.0 MW.

At sea, the turbulence levels are lower than on land. The present experience at Blyth Harbour Wind Farm, semi-offshore shows this clearly. This will lead to less wear and lower structural loads offshore. The variation in wind with height is less severe offshore, reducing the advantages of tall towers.

The turbines will need to be well protected from the wet, salty environment. There are however, plenty of turbines located on the coast, with experience of similar conditions. In the UK the average winds offshore are likely to be lower than on some of the upland wind farm sites.

Mass concrete foundations

The first offshore wind farms in the Baltic used mass concrete foundations. These particular types are unlikely to be used again as they are expensive and present a large cross section to waves. Some designers are considering the use of gravity bases where the weight is concentrated in a submerged structure below the wave zone.

This type of foundation could be floated out and ballasted on site. This foundation can require sea-bed levelling or other preparation.

Piled Concrete Foundations

The foundations for existing wind farm at Blyth were made by using a number of piles through the unreinforced concrete of the old pier into the rock underneath. A similar method was investigated for the offshore foundations. A concrete block could be cast in location and then a small piling rig would be used to connect the block to the underlying rock. This was ruled out on cost.

Pile Foundations for Rock

A British Company Seacore has pioneered techniques for drilling large diameter (up to 4m) holes in rock at sea from a jack-up rig. The same rig can install a steel monopile in the hole and grout it in place. This technique was used successfully in Sweden to install a small wind farm. One feature of this technique is that the piles can be installed very accurately.

Tripods

Fabricated steel tripod structures have been suggested. These would have lower wave cross-sections but was found to be more expensive to fabricate than other options. These could be secured to the seabed with much smaller piles than monopiles using smaller installation machinery.

Chosen Design

The Blyth offshore wind farm will be installed on a submerged rockhead 1 km offshore. The minimum water depth is 6m, the tidal range is 5m and waves of up to 8 m are expected at the site. (Previous offshore wind farms in the Baltic and elsewhere have been exposed to 0.5 m tidal range and 2 m waves at most).

The plan is to drill a large diameter hole in the rock and grout in a 3.5 m diameter monopile in place, for each turbine. The design is progressing, using the results of boreholes made last summer.

The tower natural frequencies are in the same frequency range as the loading from large waves. Large bending moments can be produced in the pile due to the wind loading from the large rotor. To analyze these and ensure that the structure can withstand the static and dynamic loads, various design techniques are being used in consultation with other engineering design teams. The foundations cannot be designed in isolation from the tower and turbine if the dynamic loads are to be calculated accurately. Wind turbine designers have little experience of wave loading and pile designers are not used to having a dynamically sensitive structure on top of the pile.

Electrical Infrastructure

The Blyth offshore wind farm is relatively simple electrically. A sub-sea cable to link the turbines together and to the shore is required. The local grid voltage is 11kV and 11kV transformers are readily available for installation inside the towers or nacelles.

To connect into the Northern Electric distribution grid, the cable will have to cross the River Blyth once it reaches the East Pier. The river is dredged at this point and the cable will have to be well buried.

Turbine Installation

Border Wind gained useful experience during the construction of the existing harbour wind farm. The installation was carried out using a floating crane and barges.

Installation costs for offshore wind farms will be much more expensive than on shore. The combination of heights and weights will require quite large vessels with their associated large hire charges. Lifts will need to be organized to happen quickly and in as wide a range of wave and wind conditions as possible. Currently available jack-up rigs can only move in 1.5 m swell, but can lift in up to 15 m/s winds.

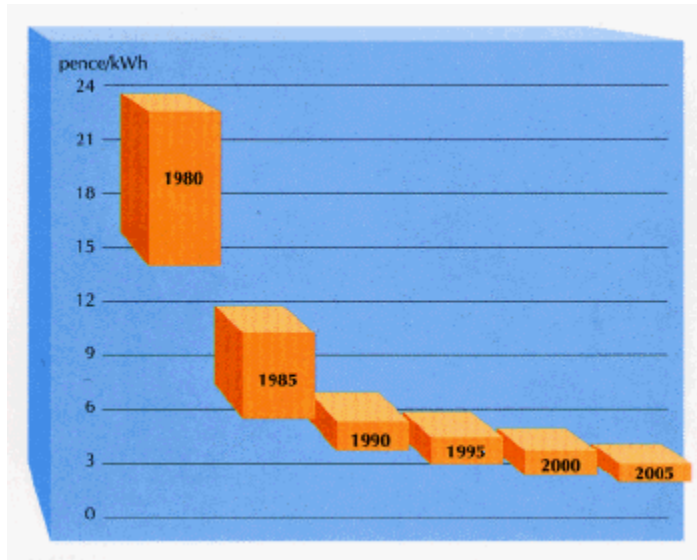
There is a suitable jack-up barge for this project. It is based in the Tyne and operated by AMEC marine. This vessel has the lift capacity required and can carry the drilling equipment for the monopiles.

Once the piles are in place the rig will return to port. The tower sections will be secure vertically on the deck and the nacelle with two blades already fitted loaded. The third blade will be stored horizontally on deck. The tower will be installed and then the rig jacked up to allow the third blade to be fitted to the rotor before the nacelle is installed.

4.2.4 Economic issues

The costs of generating electricity from wind depend mostly on the average wind speed of the site and the capital cost of the installation. The best wind turbines on the best sites can already compete with thermal power generation costs.

Between 1980 and 1995, the real cost of WTG electricity fell by 10% per year, as shown by the graph below. For Europe, wind generation costs are mostly in the range of 4 to 8 \$c/kWh. This is competitive with new nuclear and clean coal plants, but is not competitive with Combined Cycle Gas Turbines.



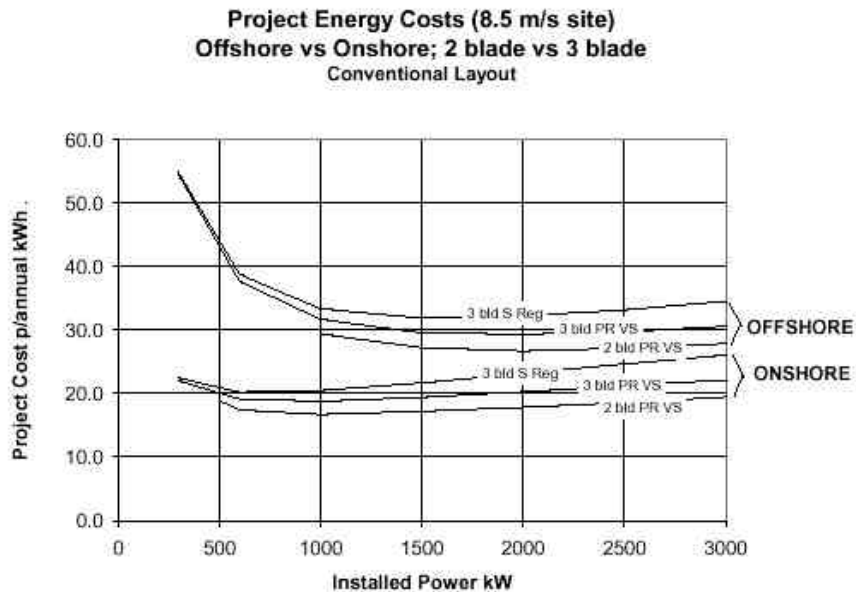
The falling cost of wind generated electricity in pence/kWh (Source: Shell Education Service)

The wind energy market is at the moment largely dependent on government support or other stimulation programmes. These are driven by environmental and other concerns, including CO₂ emissions. In response, installed wind capacity has been growing at 27% per annum over the last five years, and is expected to grow at similar rates over the next five years.

A study was carried out to find the optimum size of wind turbines¹³. The results of the analysis, for an 8.5 m/s site, are shown below. The model compares three concepts: 3 blades w/ stall regulation, 3 blades w/ pitch reg and variable slip and 2 blades w/ pitch reg and variable slip.

¹³ Wind Turbine Technology Offshore, J R C Armstrong, J A Consult (76, Dukes Avenue, London W4 2AF 0181-994-2645: johnarmstrong@jac.ndirect.co.uk)

For offshore wind turbines, the optimum size is around the 2 MW level and the benefit of the two-bladed rotor is also evident. In the analysis, rotor size is independently optimized for each value of power. The optimum 2 MW two-blader for offshore has a rotor diameter of 78m and a tower-top weight of 108t. It is about 10% more cost effective than the optimum three-blader.



Other two important factors that have made offshore wind power more attractive are:

- The maintenance interval of wind turbines has been steadily increasing, from monthly in 1990 to six monthly in 1998.
- The reliability of the turbines has also been improving during this period.

These two features are very important for the developments offshore, as access to the turbines will be difficult and expensive.

4.2.5 Environmental impact issues

Land use

While onshore wind farms are spread across large areas, the actual land that they use is low. The turbine footings use a fraction of 1% of the land. Most of the remaining land

area is physically available for use as before. There is no evidence that installed turbines interfere with normal arable or livestock farming.

Renewable energy resources are diffuse in energy content. Large surfaces are therefore required to capture the energy. Taking the total fuel cycle into account, wind energy compares favorably with a number of other energy sources in terms of energy generated per unit of land.

In the case of offshore wind farms, this problem is eliminated with the consequent benefit with respect to onshore designs.

Land required per GWh for different electricity generation technologies are:

Generation Technology	Land required per GWh for 30 years (m²)
Geothermal	400
Wind	800 – 1300
Solar Photovoltaic	3300
Solar Thermal	3600
Coal	3600
Biomass Plantations	10000

Visual effects

Onshore wind farms are highly visible. Reactions to this are subjective. The reactions to visual aspects depend strongly on the geographical location and population density. Manufacturers have attempted to improve the appearance of their machines and developers take account of visual amenity in the siting and design of their projects.

Other visual effects include the reflection or interruption of light by the rotating blades. Siting and the surface finish of the blades control these. Two bladed rotors appear to tilt with respect to the horizon and rotate faster than three bladed designs.

Again, offshore wind farms minimize this issue and therefore make it better than onshore ones.

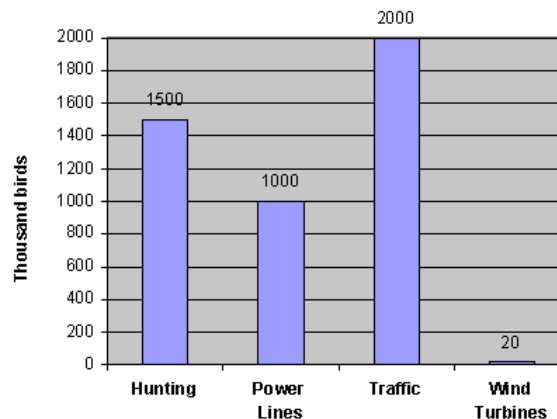
Noise

Modern wind turbines are quiet and becoming quieter. Their noise is a function of rotor speed and design, 2 bladed rotors are noisier than 3 bladed, because they rotate faster than three bladed rotors for the same energy efficiency. The sound level at 40 m from a typical modern turbine is 50 - 60 dB (A), about the same level as conversational speech. Nonetheless, the noise level affecting neighbouring houses is an important factor in wind farm siting and design.

For offshore wind farms, the noise problem is also reduced because of the obvious location, far enough from populated areas.

Bird deaths

Birds often collide with structures they have difficulty seeing. In absolute terms, wind turbines are only a minor cause of bird deaths (see Figure). Radar studies show that birds in flight deliberately avoid wind turbines during the day or night. Nonetheless industry practice is to avoid sites that are critical to birds (habitats, migration routes).



Estimated annual bird deaths - The Netherlands (Source: Shell Education Services)

5. Conclusion and future prospects of these technologies

In conclusion, I think that the most important outcomes, from the two projects analyzed, are:

For Solar Home Systems in Rural Villages

- **SHS can make a small but important contribution to climate change mitigation.** Typical SHS of 10 to 50 Wp will directly displace roughly 0.15 to 0.3 tons of CO₂ per year through fuel substitution. While modest on a per household basis, reaching the first 10% of the potential SHS market would directly offset an estimated 10 million tons of CO₂—the equivalent of Zimbabwe's 1995 fossil fuel CO₂ emissions—and extend new electric service to 35 million homes. At a 50% market penetration level, SHS would directly offset the equivalent of Switzerland's 1995 CO₂ emissions from fossil fuel.

There are also significant indirect GHG benefits from SHS dissemination including support for PV market transformation and the potential to avoid substantial grid-based emissions. Widespread use of SHS has the potential to put developing countries on a low-carbon path for rural electrification while providing an important market niche to help make PV more competitive for a range of applications worldwide.

- **SHS have a high rate of CO₂ displacement per installed Wp.** Due to the tremendous inefficiency of kerosene lighting, rural household electrification in developing countries is among the highest impact PV applications for climate change mitigation per installed Wp. Displacing kerosene lamps typically reduces far more CO₂ per installed Wp than grid-connected PV applications, in some cases by a factor of ten.
- **SHS have significant social, economic, and non-GHG environmental benefits.** SHS dramatically improve rural life by providing high quality light. By reducing the need to store and burn kerosene for lighting, SHS improve household health and safety. The systems also ease access to information and entertainment via radio

and television. Furthermore, socio-economic impact studies have found that many of the systems contribute to income generation.

- **Numerous barriers still constrain potential SHS markets.** While markets are starting develop in many countries, SHS dissemination still faces substantial constraints. Barriers include:
 - Lack of information about SHS and grid extension plans
 - Lack of capital for SHS businesses and consumer financing programs
 - Lack of trained technicians, managers and other human infrastructure needed for system delivery and maintenance

Market distortions stemming from import duties on SHS equipment and subsidies for kerosene also constrain SHS dissemination in many countries. International initiatives and host country policies can help to remove these barriers, accelerate SHS markets, and ensure that potential GHG mitigation and development benefits are realized.

For Offshore Wind Projects in UK

- **Advantages over onshore wind farms.** Many of the characteristics that a perfect site has to comply are met with offshore wind farms, while many of the problems that onshore wind farms poses are greatly reduced. Offshore wind farms can be located in places with low level of turbulence and better wind conditions leading to higher capacity factors and lower costs per kWh, they are remote from populated areas (less noise and visual effects problems) and they don't compete with other alternatives with respect to land use, leading to a better availability of sites.
- **Potential market not fully developed and with great growth potential.** At the moment, medium or small-scale wind turbines produce most of the energy generated by wind. These are situated predominantly on land (onshore). Shell believes that the future of the wind industry lies in large-scale wind farms especially in hostile environments such as offshore. These projects promise a much more

viable use of wind energy. Shell also sees great opportunities in this new market, as "real" offshore facilities do not exist yet. Shell wants to develop this new market actively in order to play a major role in it.

- **Long-term environmental benefits.** As discussed before, wind energy source reduces emissions by avoiding or displacing the use of other generating sources, old fossil generation in particular.
- **Challenge to reduce construction and maintenance costs.** Over the last two decades, wind has suffered due to changeable governmental policies related to R&D funding, tax credits and other measures. These discontinuous policy changes have affected education and training of engineers and other skilled professionals that the industry needs to improve construction and maintenance costs. Therefore it is very important to develop stable policies to contribute to the development of the windpower industry.