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ABSTRACT

We discuss energy efficiency and renewable energy investments in Eritrea from the strategic long-term economic perspective of meeting Eritrea's sustainable development goals and reducing greenhouse gas emissions. Energy efficiency and renewable energy are potentially important contributors to national productive capital accumulation, enhancement of the environment, expansion of energy services, increases in household standard of living, and improvements in health. In this study we develop a spreadsheet model for calculating some of the national benefits and costs of different levels of investment in energy efficiency and renewable energy. We then present the results of the model in terms of investment demand and investment scenario curves. These curves express the contribution that efficiency and renewable energy projects can make in terms of reduced energy sector operating expenses, and reduced carbon emissions. We provide demand and supply curves that show the rate of return, the cost of carbon emissions reductions vs. supply, and the evolution of the marginal carbon emissions per dollar of GDP for different investment levels and different fuel-type subsectors.

Keywords: Emissions scenarios; Climate change; Global warming

Introduction and Motivation

In the development of strategies and scenarios for mitigating and avoiding the potentially severe consequences of climate change, many investigators posit a strong role for improvements in energy efficiency, fuel switching, and the development of renewable energy resources. In this study, we describe new estimates of the macro-economic and sustainable development benefits and costs of energy efficiency and renewable energy (EE/RE) development at the national level for Eritrea, East Africa. This work contributes the larger effort of characterizing how different investments can contribute to low-emissions climate change mitigation scenarios by specifying measures and investments that can be taken at a national level in a small Sub-Saharan African country with low per-capita income.

The Intergovernmental Panel on Climate Change in an effort to assist policy formation that can mitigate climate change, has developed a set of long term greenhouse gas (GHG) emissions scenarios that reflect the current understanding in the literature about the driving forces underlying future GHG emissions, (Nakicenovic, et al, 2000). The IPCC classifies emissions scenarios into scenario "families" that have similar assumptions about the evolution of the economic, demographic, and technological forces that underlie emissions. The emissions scenarios with the lowest future emissions are in the "A1T" and "B1" scenario families. The A1T scenario family describes a world of rapid economic growth, with incomes in developing countries growing especially fast, and rapid development of non-fossil energy technologies. Meanwhile, the B1 scenario family also assumes fairly rapid economic and income growth in developing country economies, but--in contrast--assumes a fairly rapid shift towards a service and information economy with reductions in material intensity combined with the introduction of clean and resource-efficient technologies.

The IPCC scenarios described above are characterized mostly at the global and continental scales. For smaller developing countries, it is not obvious precisely which investments and policies can feasibly contribute to the low-emissions scenarios described in the IPCC emissions scenario analysis. This study begins the process of filling this information gap for the particular example of Eritrea, East Africa in an effort to facilitate clean energy investments, and to accelerate reductions in GHG emissions.

For African countries, the research institution that has conducted the largest number of studies regarding energy efficiency and renewable energy potentials is the African Energy Policy Research Network/Foundation for Woodstove Dissemination (AFREPREN/FWD) (See: http://www.afrepren.org/). The AFREPREN/FWD research (AFREPREN, 2004) has provided a wealth of information on the economics, potentials and barriers to renewable energy and energy efficiency development in a diversity of African countries. Most of the AFREPREN/FWD studies are specific to either particular projects or technologies. This study integrates the economic and technical features of several energy efficiency and renewable energy technologies in a macro-economic scenario model for Eritrea. This integration helps build a bridge between the technology- and project-specific information provided in AFREPREN/FWD studies and alternative futures described in the the global analysis of the IPCC GHG emissions scenario work.

Background and Issues for the Eritrean Energy Sector

In Eritrea, as in many Sub-Saharan African countries, energy services are a large part of both the monetary and non-monetary economies. It is possible that in Eritrea, as much as 20% of total expenditures, effort, and socioeconomic costs are related to energy services. Basic energy statistics for Eritrea are that 20% of households have access to electricity, 66.3% of primary energy consumption is supplied by biomass, and the major consumers of energy are households (68.3%), public/commercial (16%), transport (13%), and industry (3%). (DoE, 1998a,b; Habtetsion, 2001; Habtetsion, 2002)

According to data from Eritrean Department of Energy and International Monetary Fund sources, national purchases of petroleum products in 1997 was approximately 300 million Nakfa per year (IMF, 2000) (at an exchange rate of 7 Nakfa/USD in 1997). A volume 230,000 tonnes/year of petroleum was imported, and retail sales had a value of about 1.6 times imports or 500 million Nakfa. From 1995 to 1997 demand for petroleum products increased approximately 5% per year. Electricity production on the other hand has increased from approximately 160 GWh/year in 1996 to approximately 210 GWh/year in 1999; an average growth of about 10% per year. The retail value for this electricity is estimated at between 100 to 200 million Nakfa per year. Wood consumption was estimated at 1.8 to 2.1 million tons/year (Lahmeyer, 1997) in 1996 with consumption growth expected to approximately follow population growth of 3% per year. Even if we value the biomass used at only 100 Nakfa per ton, the value of the biomass sector consumption is about 200 million Nakfa per year, even though most of this represents non-monetary economic transactions. In summary the energy sector in Eritrea represents approximately 800 to 900 Nakfa per year of economic activity, and is probably growing at 5% to 7% per year with both population and increasing standards of living. It therefore represents a very strategic economic development sector, and it is also probably responsible for approximately 10% or more of national imports.

The energy sector also represents a very substantial portion of national infrastructure development. The recently constructed Hirgigo power plant and grid expansion project that has increased installed electricity generation capacity by 80 MW at an investment cost of at least $160 million over about five years. This represents more than $30 million per year of capital investment expenditure. In 1997 capital expenditures by the Eritrean government were 19% of gross national product, and capital investments by the private sector were 829 million Nakfa or 14% of GNP. Energy sector investments are at least 5% of GNP and represent more than 15% of national capital expenditures recently.

The macro economic data described above shows that the energy sector has a very substantial role in Eritrea's development. Energy sector investments are very important for long term economic strategy for several reasons. One reason is that the size of the energy import expenses and the drain that they provide on national balance of payments. The second reason stems from the importance that access to electricity has in economic development and improved standards of living. The effectiveness of electrification in enhancing productivity means that the pace of electricity demand growth will continue at its current rapid rate. The current electrification rate (fraction of people with access to electricity) in Eritrea is about 20%, and as complete electrification is attained, we can expect national expenditures approaching 50 to 100 USD per household per year for electricity supply. The third factor that makes energy sector development a crucial strategic issue is the fact that current and future biomass consumption is a potentially growing drain on Eritrea's ecosystem. There is rather limited biomass in Eritrea because biomass production is limited by scarce rainfall. Therefore energy sector investments that decrease biomass consumption or increase the biomass productivity of the ecosystem (e.g. reforestation programs) will have a large impact on Eritrea's future environmental capital.

Energy sector investments in the near-term will have a dramatic impact on future energy sector expenses and environmental sustainability. If there are no improvements in efficiency in the energy sector, then the rapid growth of energy demand will degrade Eritrea's environmental capital and expand Eritrea's already large international trade deficit. On the other hand if aggressive investments are made in all subsectors of energy development we believe that both substantial environmental rehabilitation can be achieved, and Eritrea's trade deficit can be improved with enhanced national capital accumulation.

The long term question for Eritrean energy sector development is: How do we optimize the long term accumulation of energy capital? We believe the answer lies in searching for the full spectrum of energy sector development activities that have both national and global environmental benefits and that result in net positive accumulation of energy resources by decreasing energy sector expenses and resource use. In this paper we provide estimates of the extent to which efficiency and renewable energy programs and investments may contribute to the development of Eritrea's energy sector, the growth of the Eritrean economy, and mitigation of global climate change.

Not only do efficiency and renewable energy investments help increase net national accumulation of capital by decreasing oil imports and biomass harvest, but they also provide opportunities for obtaining access to new sources of international capital and finance at concessionary rates. The lower cost of international financing for EE/RE investments arises because of the international environmental benefits that can accrue from Eritrean EE/RE projects.

In the following discussion, we first describe an energy sector scenario model and the assumptions and inputs used in the model. We also describe the range of scenarios and policies considered, and cost estimates and forecasts assumed for energy efficiency and renewable energy technologies. We present model results by first providing a summary of the forecasted economic benefits and costs for the various scenarios. We then present supply/demand curves for investment, and carbon emissions reduction costs. We also describe the forecasts of marginal carbon intensity of economic growth for Eritrea under the different investment and policy scenarios. We conclude with a discussion of the national CO2 emissions reduction potential, possible national investment rates for EE/RE development, and which EE/RE investments are likely to be most beneficial.

Energy Sector Scenario Model for Eritrea

In this section we describe the energy sector scenario spreadsheet model that we developed for Eritrea. The model is implemented as an Excel spreadsheet. This model keeps an accounting of the different subsectors of energy development, and estimates costs and benefits of different energy development strategies. The model does this by using population and income as exogenous drivers for energy services demand. Fuel prices and technology costs are inputs. Policy investment scenarios are specified in terms of efficiency improvement levels or rates and technology costs that depend on the amount of efficiency improvement. The model includes a simple biomass stock accounting model that provides estimates of carbon stock changes resulting from biomass subsector efficiency improvements and reforestation/restoration activities.

The energy use is modeled from 1950 to 2100 in order to provide both backcasts, and forecasts, and in order to provide output for the entire IPCC emissions scenario forecast period.

Model Structure and Economic Assumptions

The model takes exogenous projections of population and income, assumes simple relationships between energy services demand, income, and fuel market shares and builds a national accounting of energy use for each of three energy subsectors: electricity, oil, and biomass.

Two of the key exogenous drivers of energy demand are population and economic growth. Long term economic growth rates are particularly difficult to predict, this is especially true for a country like Eritrea which became officially independent in 1993. As reported by the International Monetary Fund (IMF, 2000, p. 24) the average real annual GDP growth in Eritrea from 1995 to 1999 inclusive is 4.9%. This is likely to be slightly higher than a sustained long-term average because of the accelerated economic activity that arises from post-independence reconstruction. Thus our baseline case assumes a 4% long term average annual GDP growth.

With respect to population growth estimates and forecasts for Eritrea vary substantially. The population forecast used in the model is derived from forecasts from the United Nations (UN) forecasts (United Nations Department of Economic and Social Affairs, Population Division, 1998). The trend in population growth rate decline indicated in UN population forecasts was extrapolated to 2065. At 2065, the extrapolated population growth rate trend forecasts a stabilized population (zero growth), which our model extrapolates to the end of the forecast period at 2100. The general effect of changes in the population growth forecasts in our model will be to scale up and down the base case energy consumption, costs and savings, while the relative impact of different policy and investment scenarios remains largely unchanged.

Another key issue in specifying a long-term energy sector base case is defining Eritrea's long-term development path. The B1 IPCC scenarios for example assume a rather rapid shift towards a service-oriented information economy, while other scenarios assume a more business-as-usual industrial development path. Eritrea as a fairly small, isolated country with high energy costs and limited export industrial development potential is likely to be fairly constrained in the medium-term development path it can choose. A majority of future economic growth will likely be used to supply domestic demand. The Eritrean government is facilitating oil and gas exploration, examining the potential of geothermal energy generation, and open to utilizing excellent wind energy resources as a driver to export-oriented industrial growth, but these scenarios are fairly speculative at this stage, and thus beyond the scope of the present study.

Given the above considerations, in the model we make the following assumptions regarding exogenous drivers of energy demand in Eritrea:

- **Population:** Population growth has been 3.0% per year from 1950 to 1996, and that from 1996 to 2065 the population growth rate decreases by 0.042% per year until 2065 when the population stablizes and becomes constant.

- **Income:** National real income growth is 4% per year and per-capita income was $200/capita/year in 1992.

- **Electrification:** The fraction of the population with electricity increased 0.3% per year from 1950 to 1996. The fraction of people with electricity in 1996 was 20%, and that from 1996 to 2100 the fraction of people without electricity decreases 2% per year (when compared to the faction without electricity the previous year).

- **Biomass Consumption:** The per-capita biomass consumption for cooking, heating, and water heating under traditional conditions is 0.6 metric tons per year, and that all households without electricity use primarily biomass for these end-uses. For houses with electricity, we assume that half of the energy services demand for cooking and water heating continues to be supplied with biomass.

- **Electricity Consumption:** Electricity consumption is proportional to the fraction of people with electricity service, the population, the per-capita income, and inversely proportional to an electric sector efficiency factor.

- **Oil Consumption:** Oil consumption is proportional to national income, and inversely proportional to an oil sector efficiency factor.

- **Biomass Production:** National primary biomass production is 15 million metric tons per year.

- **Biomass Stocks:** We assume an apportionment of 30%, 25%, 20%, 15%, 7.5%, and 2.5% of national primary biomass production goes into ecological stocks that have mean lifetimes of 1, 3, 5, 10, 20 and 50 years respectively when undisturbed by household energy use under baseline land use conditions.

- **Biomass Harvesting:** Households harvest their biomass fuel from different ages of stock proportional to the amount of biomass resident in that age of stock.

- **Initial Biomass Stocks:** In 1950 (for an initial condition of the biomass stock calculation) the biomass stock is in equilibrium with conditions of no human harvesting under baseline land use conditions.

Additional data inputs for the model include a 1998 population of approximately 3,577,000 (from the UNDP), and electricity consumption of 162.5 Gigawatt-hours in 1996.

With these assumptions we can make rough estimates of future emissions and compare alternative scenarios that correspond to different levels of investments in efficiency and renewable energy development. For calculating present values we use a real discount rate of 6% that corresponds to a nominal discount rate of 9% with 3% inflation. This is approximately the public policy discount rate in Eritrea.

Scenarios and Policies

In our macro economic energy sector development model, we analyze the impacts from the six categories of subsectoral programs and policies: (1) Biomass End-Use Efficiency, (2) Reforestation, and Ecosystem Restoration, (3) Electricity System and Appliance Efficiency, (4) Petroleum Subsector Efficiency, (5) Wind Energy Development, and (6) Solar Photovoltaic Development.

We develop five scenarios with different levels of effort in these six energy efficiency and renewable energy (EE/RE) program areas. The five scenarios include:

1. **Baseline Scenario:** This is a business as usual scenario that would result from the unimpeded action of market forces with little Eritrean government and international donor intervention.

2. **Moderate EE/RE Scenario:** This scenario represents a moderate amount of effort and investment in energy efficiency and renewable energy technologies. This scenario probably best represents the present policy path in Eritrea. The Eritrean government shows substantial interest in efficiency and renewable energy but has fairly limited capital and expertise for implementing aggressive programs so present programs are moderately aggressive.

3. **High EE/RE Scenario:** This scenario represents what may be possible with a further acceleration of interest and investment in energy efficiency and renewable energy activities in Eritrea.
4. **Very High EE/RE Scenario:** This scenario probably represents the maximum technically feasible energy efficiency and renewable energy path given current knowledge regarding efficiency and renewable energy technologies. Further advances may be possible given future technological breakthroughs.

For biomass subsector efficiency, we assume a national program to replace existing biomass stoves with higher efficiency models that is implemented in two phases. Each biomass efficiency program has a beginning year, an ending ramp-up year (when the program is operating at maximum dissemination), and a final dissemination rate. The more aggressive the program the higher the per-capita cost. The details of program parameters for the four scenarios are provided in table 1.

In the model, we formulate the impacts of reforestation as a change in the age distribution of primary biomass production. The baseline average age of primary biomass production is 6.3 years. For the reforestation distribution, the average age of produced biomass is 9.0 years with 16%, 20%, 25%, 20%, 15%, and 4% of national primary biomass production going into ecological stocks that have mean lifetimes of 1, 3, 5, 10, 20 and 50 years respectively. The fraction of biomass production assumed to occur in reforested areas is assumed to increase linearly with time, with the final year 2100 fraction changing under the four scenarios. This final reforest fraction is assumed to be 0%, 50%, 75%, and 100% for the baseline, moderate EE/RE, high EE/RE, and very high EE/RE scenarios respectively.

For both petroleum and electricity subsector efficiency, we assume that with no policy intervention only extremely profitable energy efficiency investments are made in the energy sector. We translate this assumption into an assumed subsector efficiency improvement rate of 0.25% per year with efficiency investments obtaining a 100% return on investment in the base case. In the policy cases we assume that standards and education can improve the efficiency of subsector energy use by about 0.5%, 1%, and 1.5% per year for the moderate, high and very high EE/RE scenarios respectively. For these different efficiency innovation rates, we assume that the average return on efficiency investments decreases to 50%, 30%, and 15% respectively. We then calculate the annual investment cost for efficiency by calculating the operating cost savings from the annual improvement in efficiency and dividing by the assumed return rate.

For wind energy development, we assume that the fraction of electricity not supplied by wind turbines decreases by 0.10%/year in the base case. For the policy cases we assume that the fraction of electricity not supplied by wind decreases by 0.5%, 1.0%, and 1.5%/year respectively for the moderate EE/RE, high EE/RE, and very high EE/RE scenarios respectively. In all cases the starting year for wind development is assumed to be 2005. The assumed capacity factor for the wind turbines is 30% and the capital investment cost is assumed to be $1500 per kilowatt of rated capacity in 2000 with a annual real decline in the cost of wind energy investments of 1%/year.

For solar photovoltaic development, we assume that the fraction of electricity supplied by solar photovoltaic systems increased by 0.01%/year in the base case. For the policy cases we assume that the fraction of electricity supplied by solar increases by 0.03%, 0.06% and 0.10% per year respectively for the medium EE/RE, high EE/RE, and very high EE/RE cases respectively. In all cases, the starting year for solar development is assumed to be 1993, but the policy case growth rate is not implemented until 2001. The assumed capacity factor for the solar system is 25% and the capital investment cost is assumed to be $6000 per kilowatt of rated capacity in 2000 with an annual real decline in the cost of solar systems of 2%/year.

Model Results

Our macroeconomic energy sector development model provides approximate forecasts of CO_2 emissions, capital investment rates, rates of return for subsectoral investments, costs of CO_2 emissions reductions, and both average and marginal CO_2 emissions intensities. In this section, we provide a description of these results and a comparison of the performance of the different EE/RE programs. We express our scenario forecast results in several different ways: First we illustrate the projected annual capital and operating expenditures, benefits, and costs for the different scenarios. Next, we calculate supply curves for CO_2 emissions reduction, energy savings, and investment rate of return. And third, we illustrate results in terms of emissions intensities, and investment intensities per dollar of national GDP.

Summary of Benefits and Costs

Fundamentally, investments in energy efficiency and renewable energy substitute capital investment for resource use. Efficiency is primarily accomplished by purchasing better designed, and usually more expensive appliances that have lower energy using requirements. Renewable energy uses local energy resources like wind and solar that are supplied essentially for free with little extraction and transport costs (beyond what may be required for transmission to point of use). With greater levels of EE/RE development more capital is invested while operating expenses--especially the expense of imported oil--for the energy sector decrease.

Figure 1 illustrates the reduction in annual non-renewable energy expenditures as percent of national GDP for the four scenarios analyzed in this study. The highest operating expenses correspond to the baseline scenario, were we estimate that as much as 20% of GDP may be currently spent on energy services activities when one adds the monetized value of the time and effort spent collecting wood and dung for household cooking and water heating. In the baseline scenario, the proportion of time and energy spent on energy services is forecast to decrease from 22% to 16% over the next century as the economy grows faster than the demand for energy services. Our forecast also assumes constant real unit prices for energy, implying that if real prices decline, then the fraction of GDP spent on energy services may decline faster than this. The three policy scenarios show progressively more rapid declines in the expenditure for non-renewable energy supplies, with declines to 12%, 8%, and 5% of GDP respectively for the moderate, high, and very high EE/RE scenarios respectively.

As energy efficiency and renewable energy investments substitute capital investment for biomass and fossil fuel expenditures, the energy-related carbon emissions of Eritrea are forecasted to decrease. This is shown in Figure 2. Figure 2 shows the energy-related carbon emissions forecast for Eritrea from 2000 to 2100 for the four analyzed scenarios. The base case shows a rather dramatic increase in emissions as both the population and the economy increase over the period. During the period the economy is forecast to increase by a factor of 50 while carbon emissions are forecast to increase by a factor of 25. For the three policy scenarios, carbon emissions in 2100 are forecast to be more contained with a 100-year increase of CO_2 emissions by factors of approximately 15, 10, and 5 for the moderate, high and very high EE/RE scenarios respectively.

It is instructive to examine the carbon emissions reductions for the different energy subsectors in order to see which policies can make the largest near-term and long-term impact on emissions reductions. Figure 3 shows the component carbon emissions reductions for the very high EE/RE scenario. Figure 3 illustrates how biomass subsector improvements provide by far the largest emissions reductions between now and 2030 while electricity and oil sector efficiency improvements have the greatest potential for improvements in carbon emissions reductions beyond 2030. Wind energy may make a continuing, steady contribution to emissions reductions but is substantially smaller than the contribution from efficiency improvements. This picture would change slightly if wind was used to fuel export-oriented industrial production, in which case it could result in emissions reductions for global industrial production rather than just the domestic Eritrean electricity market.

Our scenario forecast model keeps an accounting of biomass stocks in order to understand the connection between fuel demand and ecosystem biomass depletion, and as a way of estimating the carbon emissions reductions from improved biomass subsector efficiency. Figure 4 shows how the forecast for biomass stocks increases as we proceed from the baseline, to the medium, high, and very high EE/RE scenarios respectively. Without improvements in biomass sector efficiency the depletion of biomass tracks the growth in the population of people that rely on biomass energy supplies. Eventually with electrification and decreasing population growth, this demand levels off and reverses, but biomass stock depletion does not bottom out until 2065 if there are no active policy or program interventions. As we proceed from less to more aggressive biomass efficiency and reforestation programs, the biomass depletion in the Eritrean ecosystem stops and reverses at earlier date, with depletion reversing as soon at 2012 with the most aggressive scenario. Reforestation also allows a net increase in ecosystem biomass, with a net increase of nearly 50% over the next one hundred years in the most aggressive scenario.

Supply Curves

We next illustrate our preliminary estimate of the development and investment potential for efficiency and renewable energy in the Eritrean economy by drawing supply and demand curves for efficiency and renewables investment.

A demand curve shows how demand increases with decreasing price. In this particular case, the product in demand by for Eritrea's clean energy development is investment capital. The demand curve is often plotted together with the supply curve to show the economic relationship between supply and demand. A supply curve shows how increasing price enables suppliers to provide more volume of product supply given their marginal production costs. Where the supply and demand curve intersects is in theory the optimum match between supply and demand. Or alternatively if demand is inelastic, the volume of demand combined with a cost minimization objective defines the minimum possible production cost of a supplied commodity.

Figure 5 shows the CO_2 emissions reduction supply curve for the Eritrean energy sector according to our scenario calculations. The emissions reduction supply curve is fit very well by an exponential trendline. Biomass sector efficiency and reforestation improvements provide the most economical emissions reductions at $6 to $20 per ton Carbon (t-C). The less aggressive efficiency improvements for the electricity and oil sectors provide emissions reductions at a cost of $35 to $60 per t-C. Wind energy provides carbon reductions at $145/t-C, while solar PV displacing diesel generated electricity comes in at $500/t-C. Currently, Eritrea is able to sell CO_2 emissions reductions at a rate of about 1000 t-C/year at a price of about $20/t-C. The difference between the $20/t-C price and the minimum $6/t-C cost arises due to the high transaction cost of the small sales volume and program implementation overheads. The calculated emissions reduction supply curve shows that it may be possible to expand the carbon emissions sales up to a rate as high as 200,000 t-C/year at a price of $20/t-C but that the most economical credits would come almost exclusively from the biomass sector. Impediments to such a carbon emissions reduction credit expansion may include transaction costs, marketing, monitoring and verification risk, and the limited local organizational ability infrastructure for expanding biomass efficiency programs.

With regards to energy sector investment and development, the Eritrean energy sector has a demand for investment capital. Local private investors, foreign private investors, the government, development aid agencies and banks all supply investment capital and financing for economic and energy sector development investments. The government's macro-economic policy has the goal of setting terms and conditions for investments that promote the optimum long-term economic development of the country. Knowledge of the energy sector demand curve for clean energy development can help aid in the formulation of such policies.

For capital supply and demand, the price of capital is the interest rate or the rate of return. Banks and investors (capital suppliers) require an interest payment or profit in return for their investment capital. The interest rate or rate return on capital also is an indication of how different investments help accumulate national assets that can contribute to macro-economic growth. National economies, countries, and investment projects provide revenues that represent a rate of return for the investment capital they demand. In any given period, as the amount of investment goes up, it gets harder and harder to generate new revenues with each added investment dollar, and the rate of return decreases with increasing investment levels. The optimum investment level is one that provides the desired rate of return given the goals and risks of the project.

Ideally, one sets optimum investment rates based on the balance or intersection of capital investment supply and demand curves. But for Eritrea (and most countries), the supply curves for energy sector capital are quite complex. The Eritrean government provides some budget for national capital investment that can be recovered through future increases in tax revenues (which exist as both monetary income and sales taxes, and non-monetary national service labor/commitments in the case of Eritrea). International lenders and financial institutions provide loans at concessionary rates for sectoral development projects. Interest rate subsidies of these international loans reflect the particular policy objectives of the international institutions. Meanwhile, NGO's and foreign governments provide development grants that can be invested in energy development projects. Private capital is also available from both the banking system and private investors. Each different capital source has a different capital supply curve that varies depending on the characteristics of the particular energy development subsector. An analysis of the intricacies of Eritrean energy sector capital supply is beyond the scope of the present study.

On the other hand, our scenario model can provide a relatively clear picture of energy sector demand by examining the internal rate of return for energy subsector developments at the margin. The EE/RE investment supply curve for Eritrea is shown in Figure 6. This curve is calculated by estimating the internal rate of return (IRR) for incremental net revenues for different subsectoral projects, and then ordering the data from highest marginal IRR to lowest marginal IRR while calculating the cumulative annual investment rate. The curve shows that end-use efficiency projects provide the highest IRR's, with the biomass sector projects providing IRR's above 100%. Next come the less aggressive electricity and oil sector efficiency projects, and then the solar and wind energy projects. If end-use efficiency projects can be done with an IRR as low as 10%, then the investment potential for EE/RE projects may increase to as much as $25 million/year over the 2000 - 2030 period.

Investment and Emissions Intensities

Since economic activity and growth is probably the most important driver for investment and CO_2 emissions, we examine investment and emissions intensities per unit of economic activity as key model outputs. Investment and emissions intensities factor out economic growth effects to first order and measure the relative level of development effort in the case of investment intensity, and the incremental progress towards emissions reduction in the case of emissions intensity.

Our intensity values are measured by taking a quantity and dividing by economic production. The intensity of EE/RE investments is measured as a percentage of gross domestic product. We measure emissions intensity in units of kilograms carbon per US dollar of gross domestic product (GDP). The model calculates two types of emissions intensities. One is the average energy sector emissions intensity that is defined as total energy sector CO_2 emissions divided by GDP. But because changing existing energy infrastructure and habits takes time, a more sensitive indicator of progress towards emissions reductions is the marginal emissions intensity. We define the marginal emissions intensity as the incremental growth in energy sector emissions, divided by the incremental growth in GDP. Decreasing emissions in the face of a growing economy requires a negative marginal emissions intensity.

Figure 7 illustrates the investment intensities for the three policy case scenarios, and an estimate of the actual Eritrean EE/RE investment intensity for the near-term. The actual investment intensity estimate shows that Eritrea is currently making EE/RE investments at the level of the moderate EE/RE scenario and the investment intensity may accelerate in the next few years. Much of the forecast near-term increase in investment intensity comes from wind energy development, expansion of improved stove programs, and electricity system efficiency improvements that are likely to be funded by the World Bank. It is possible that there are other planned investments and efforts not yet known by the author. Specifically, an actual accounting of likely electricity and oil sector demand-side investments has not yet been done. Examining the trend in the near-term forecast of the actual investment intensity, it may be quite possible to make a transition to the high EE/RE investment intensity rate of nearly 0.8% GDP/year in the next 10-20 years. The investment rate of the very high EE/RE scenario appears out of reach for Eritrea in the near to medium term, unless more information on demand-side electricity and oil subsector efficiency indicates a much more rapid efficiency improvement rate than what is currently known.

The average and marginal energy sector CO_2 emissions intensities for the Eritrean economy for the four modeled scenarios are shown in figures 8 and 9. These emission intensities include land use change and forestry effects which are responsible for approximately 60% of energy sector emissions in the year 2000, and 0% of energy sector emissions in 2060 in the baseline scenario. The marginal emissions intensity for the baseline scenario--which is dominated by fossil fuel use--is the typical value for low-income developing countries of slightly more than 0.3 kg-C/USD. In the near-term, the emissions reduction possibilities are dominated by biomass sector improvements which can turn marginal emissions intensities for the Eritrean economy negative, if they are pursued aggressively. Over the longer term, maintaining negative marginal energy sector CO_2 intensities will require more rapid conversion to carbonless technologies than what we have thus far considered. But if such technologies (such as wind-generated hydrogen) can be developed over the next 20-40 years and effectively transferred to Eritrea, then Eritrea holds the potential for doing more than its fair share to solve global climate change problems.

Conclusion

In this study we have investigated a range of energy efficiency and renewable energy development scenarios for Eritrea, East Africa. We have found that over the next several decades that it is possible to drastically reduce CO_2 emissions from Eritrea relative to a business-as-usual baseline while maintaining very high rates of return from a national perspective. We find that near-term reductions in CO_2 can most practically be obtained from increased biomass energy consumption efficiency and from reforestation programs. Over the longer term, efficiency improvements in both the oil and electricity sectors can play an important role in CO_2 emissions reductions relative to the baseline scenario. Wind and solar energy development can also make significant contributions to energy supply.

We formulated four main scenarios for energy efficiency and renewable energy development labeled by the relative level of effort: (1) Baseline/Business-As-Usual, (2) Moderate Energy Efficiency and Renewable Energy (EE/RE), (3) High EE/RE, and (4) Very High EE/RE. The baseline scenario includes some increases in energy efficiency and renewable energy, but assumes a continued primary reliance on fossil fuels. In the baseline scenario with continued population and economic growth, Eritrean CO_2 emissions are forecast to increase by a factor of 25 over the next century as the economy expands by a factor of 50, while biomass stocks in the ecosystem are forecast to undergo a further net 30% depletion. This baseline scenario is obviously unsustainable and effective energy policies will drastically reduce emissions relative to such a scenario. In the moderate EE/RE scenario, CO_2 emissions will increase by a factor of 15 over the next century while biomass stocks will hit a nadir in 2040 gradually recovering throughout the rest of the century to a level 10% higher than the present. The annual incremental investment rate required to implement a moderate EE/RE scenario relative to the baseline case is approximately 0.35% of national GDP. For the high EE/RE scenario, CO_2 emissions increase by a factor of 10 over the next century while biomass stocks hit their nadir in 2020, increasing gradually afterwards to a level nearly 30% higher than the present by 2100. The annual incremental investment rate for this scenario peaks at about 0.9% of GDP just before 2030 and then decreases gradually to to 0.36% of GDP by 2100 due to the decreasing energy requirements of the economy resulting from efficiency improvements. For the very high EE/RE scenario, CO_2 emissions still increase by more than a factor 5, over the next century while the economy has increased by a factor of 50. Recovery and enhancement of biomass stocks results in over 45% more stored biomass by the end of the century than at the beginning. In this very aggressive scenario, annual incremental investment rates rise to nearly 2% of GDP very quickly, declining to 0.5% of GDP by the end of the century.

This energy efficiency and renewable energy development modeling exercise will assist the Eritrean government, donors, international financial institutions, and NGO's in making intelligent choices regarding what is the optimum investment level for EE/RE development in Eritrea. This will also aid in determining the best allocation of investment resources for the different Eritrean energy subsectors. Our modeling indicates that biomass sector efficiency and reforestation are the subsectors that have the most substantial benefits, both in terms of aggregate rate of return (for the country), and CO_2 emissions reduction. Electricity and oil subsector efficiency follow directly behind in terms of benefits and emissions reduction potential. Wind energy provides substantial potential long-term benefits, while solar photovoltaics does not provide for a large volume of potential emissions reductions, but may have acceptable economics for particular submarkets and applications in Eritrea.

Planning for optimum sustainable development is inherently a dynamic process. Future research will attempt to expand the types of wind and solar projects under consideration, and enhance detail regarding the biomass, electricity, and oil sector efficiency improvement potential.

DISCLAIMER

REFERENCES

AFREPREN/FWD, (2004) ***AFREPREN List of Publications***, , African Energy Policy Research Network/Foundation for Woodstove Dissemination (AFREPREN/FWD), Elgeyo Marakwet Close, P.O. Box 30979, 00100 GPO Nairobi, Kenya, URL: http://www.afrepren.org/Pubs/pubslist.htm

Department of Energy (DoE), (1998a) Energy Sector Report for 1997, Ministry of Energy and Mines, Asmara, Eritrea

Department of Energy (DoE), (1998b) Updating the Energy Database of 1995 for the year 1998, Ministry of Energy and Mines, Asmara, Eritrea

Nakicenovic, N. et al, (2000) ***IPCC Special Report on Emissions Scenarios: A special report of working group III of the Intergovernmental Panel on Climate Change*** , Cambridge University Press, Cambridge, URL: http://www.grida.no/climate/ipcc/emission/

International Monetary Fund, (2000) ***Eritrea: Statistical Appendix***, International Monetary Fund, Series: IMF Country Report, No. 00/55, May 11, 2000, No. ISCREA0055, 59pp, URL: http://www.imf.org/external/pubs/ft/scr/2000/cr0055.pdf

Lahmeyer International, (1997) ***Strengthening the Department of Energy***, Lahmeyer International, Final Report, April 1997

United Nations Department of Economic and Social Affairs, Population Division, (1998) ***World Population Prospects: The 1998 Revision***, http://www.undp.org/popin/wdtrends/p98/fp98.htm, downloaded April 2001.

TABLE 1: Biomass Energy Sector Model Parameters

Description	**Baseline**	**Moderate EE/RE**	**High EE/RE**	**Very High EE/RE**
Phase I Beginning Year Biomass Program	2000	2000	2000	2000
Phase I Ending Ramp-up Year	2030	2030	2020	2015
Phase I Maximum Dissemination Rate	0%/year	4%/year	6%/year	10%/year
Phase I Biomass Program Cost	$0/capita	$2/capita	$4/capita	$6/capita
Phase I Post-Program Biomass Use	0.6 Mt/cap/year	0.4 Mt/cap/year	0.3 Mt/cap/year	0.25 Mt/cap/year
Phase II Beginning Year Biomass Program	2030	2030	2020	2015
Phase II Ending Ramp-up Year	2050	2050	2030	2025
Phase II Maximum Dissemination Rate	0%/year	4%/year	6%/year	10%/year
Phase II Biomass Program Cost	$0/capita	$2/capita	$4/capita	$6/capita
Phase II Post-Program Biomass Use	0.6 Mt/cap/year	0.25 Mt/cap/year	0.2 Mt/cap/year	0.15 Mt/cap/year

Figure 1: Forecast energy sector expenditures as a fraction of GDP. Forecasts are provided for both Base Case and Policy Case scenarios. Base Case scenario is the blue line, and Policy case scenarios are represented by symbols, with the red squares, purple triangles, and green asterisks representing the moderate, high, and very high EE/RE development scenarios respectively.

Figure 2: The 100-year carbon emissions forecast for the electricity, oil, and biomass sectors for Eritrea in millions of metric tons (Mt) of carbon per year. Note the rapid increase in emissions due to both population an economic growth in the baseline scenario.

Figure 3: The 50-year carbon emissions reduction forecast for the energy subsectors for the very high EE/RE scenario. This plot shows the large role of biomass in reducing emissions before 2030, and how after 2030 electricity and oil sector efficiency should become much more important for carbon emissions reductions in Eritrea.

Figure 4: The 100-year forecast of total biomass stocks. The figure illustrates the current estimate of net biomass depletion. Also illustrated is how depending on the scenario, the reversal date for net depletion may occur in 2065, 2040, 2020, and 2012 for the baseline, moderate, high, and very high EE/RE scenarios respectively.

Figure 5: The CO_2 emissions supply curve for the Eritrean energy sector from the present to 2050. Different subsector activities are shown with distinct symbols, and prices are show in dollars per metric tonne of carbon.

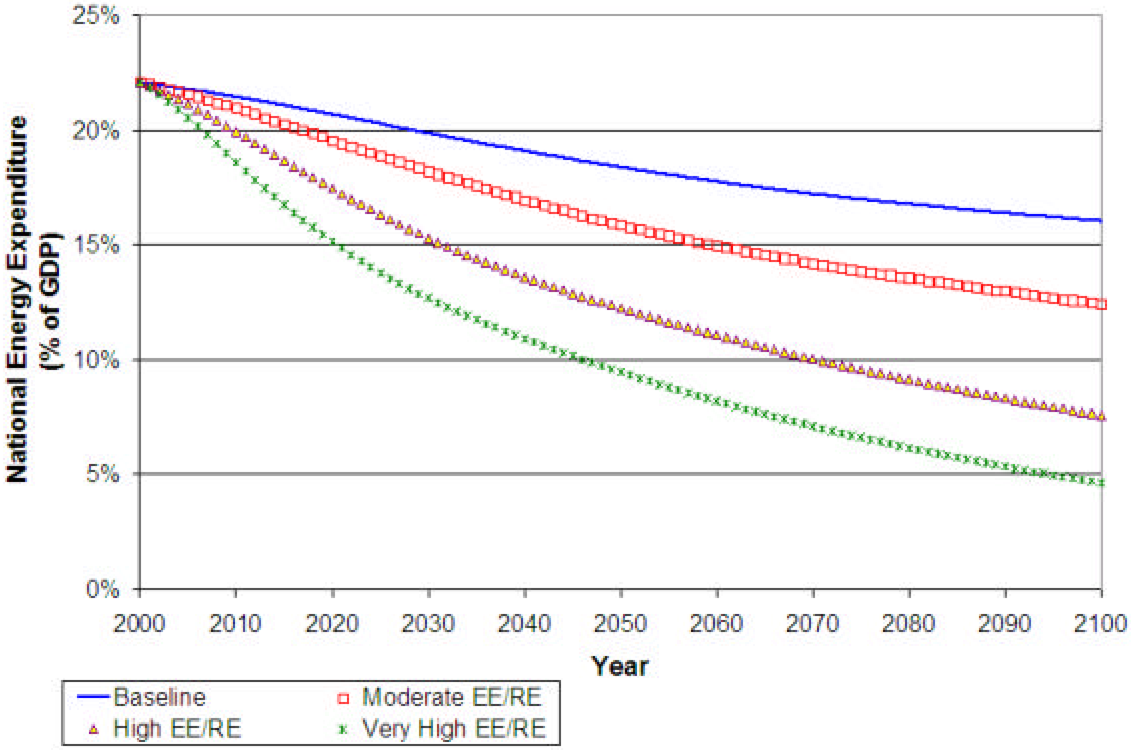
Figure 6: The energy efficiency and renewable energy (EE/RE) capital investment demand curve for Eritrea. This demand curve shows marginal investment internal rate of a return (IRR) as a function of cumulative capital investment in EE/RE assuming that projects with the highest rates of return are implemented first. Distinct symbols are used for plotting the IRR for different subsectors. The data conforms to a power law trend line with a high degree of correlation.

Figure 7: Forecast energy efficiency and renewable energy sector investment intensit as a percentage of GDP. Forecasts are provided for both the actual near-term investment intensity and the three Policy Case scenarios. The blue line represents a rough forecast of the actual EE/RE investment intensity. The Policy case scenarios are represented by symbols, with the red squares, purple triangles, and green asterisks representing the moderate, high, and very high EE/RE development scenarios respectively.

Figure 8: Average CO_2 emissions intensity for the Eritrean energy sector including land use change and forestry (LUCF). From top to bottom the curves represent the baseline, moderate EE/RE, high EE/RE, and very high EE/RE scenarios respectively.

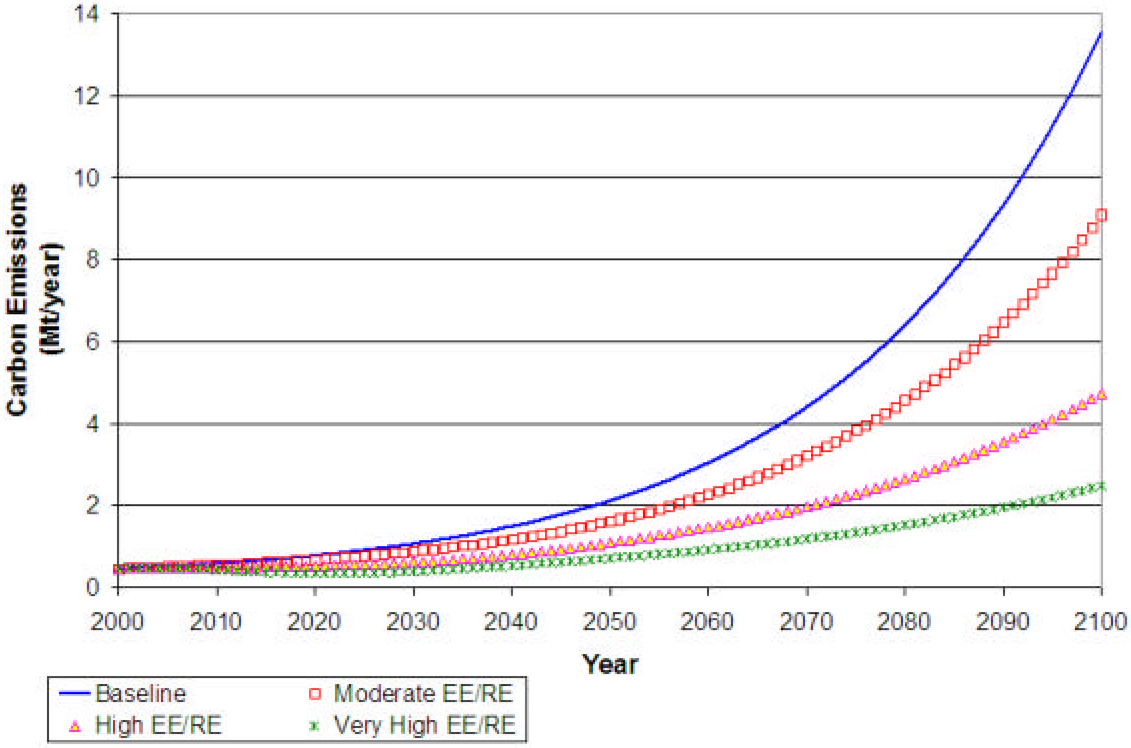
Figure 9: Marginal CO_2 emissions intensity for the Eritrean energy sector including land use change and forestry (LUCF). From top to bottom the curves represent the baseline, moderate EE/RE, high EE/RE, and very high EE/RE scenarios respectively.

Figure 1



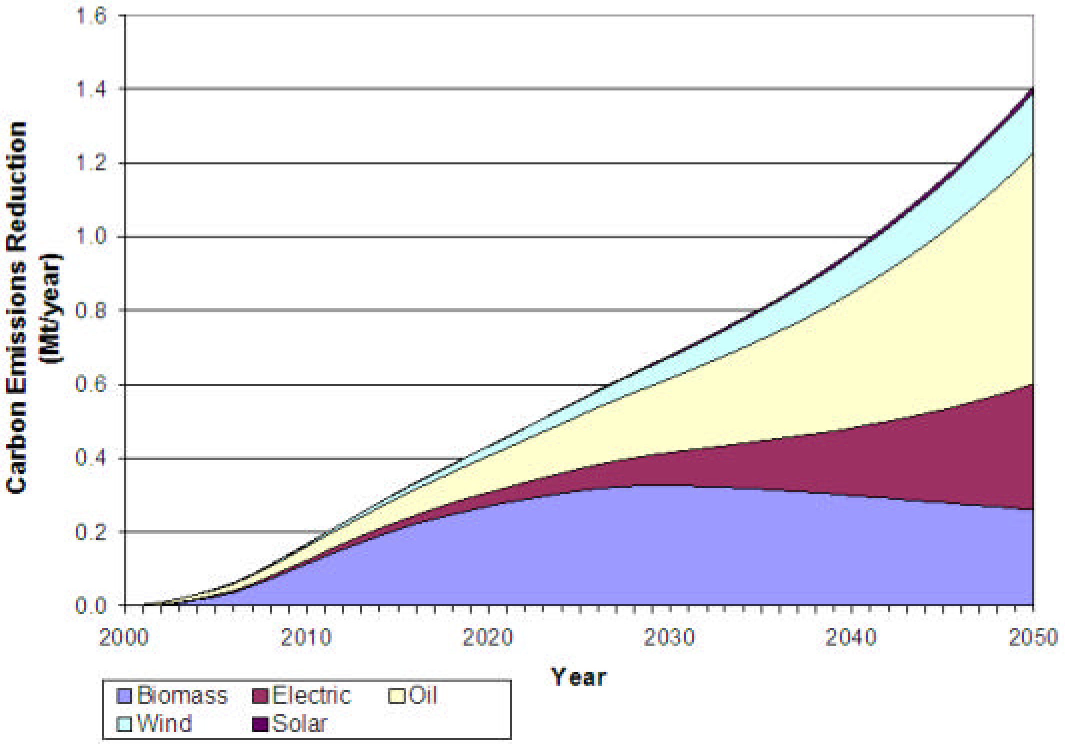
25%
20%
15%
10%
5%
0%
National Energy Expenditure (% of GDP)
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Year
Baseline
Moderate EE/RE
High EE/RE
Very High EE/RE

Figure 2



Carbon Emissions (Mt/year)
14
12
10
8
6
4
2
0
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Year
Baseline
Moderate EE/RE
High EE/RE
Very High EE/RE

Figure 3



Carbon Emissions Reduction (Mt/year)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
2000
2010
2020
2030
2040
2050
Year
Biomass
Electric
Oil
Wind
Solar

Figure 4

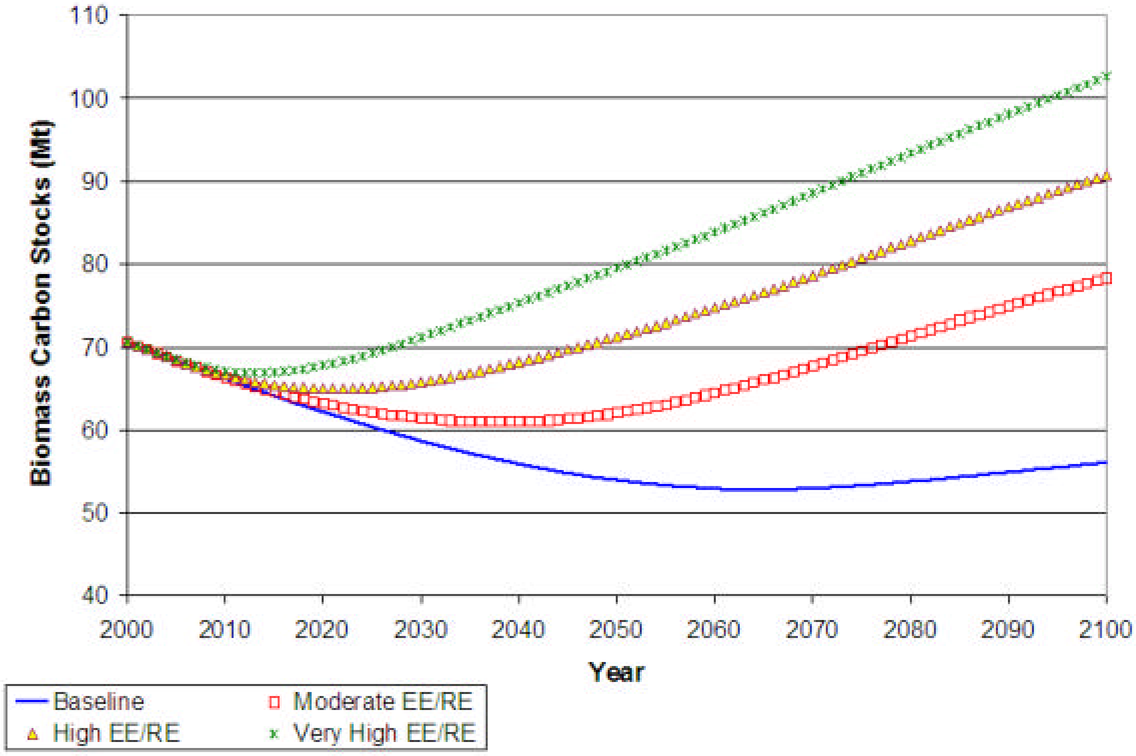

110
100
90
80
70
60
50
40
Biomass Carbon Stocks (Mt)
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Year
Baseline
Moderate EE/RE
High EE/RE
Very High EE/RE

Figure 5

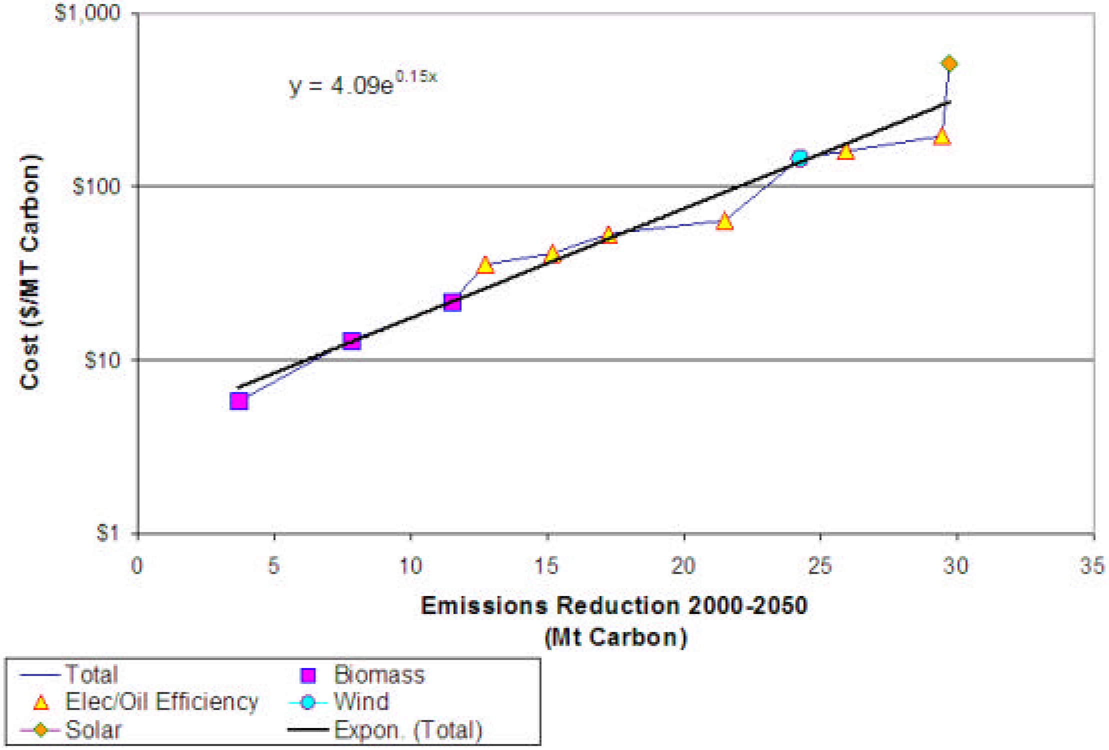

y = 4.09e^0.15x
Cost ($/MT Carbon)
$1,000
$100
$10
$1
0
5
10
15
20
25
30
35
Emissions Reduction 2000-2050
(Mt Carbon)
Total
Biomass
Elec/Oil Efficiency
Wind
Solar
Expon. (Total)

Figure 6

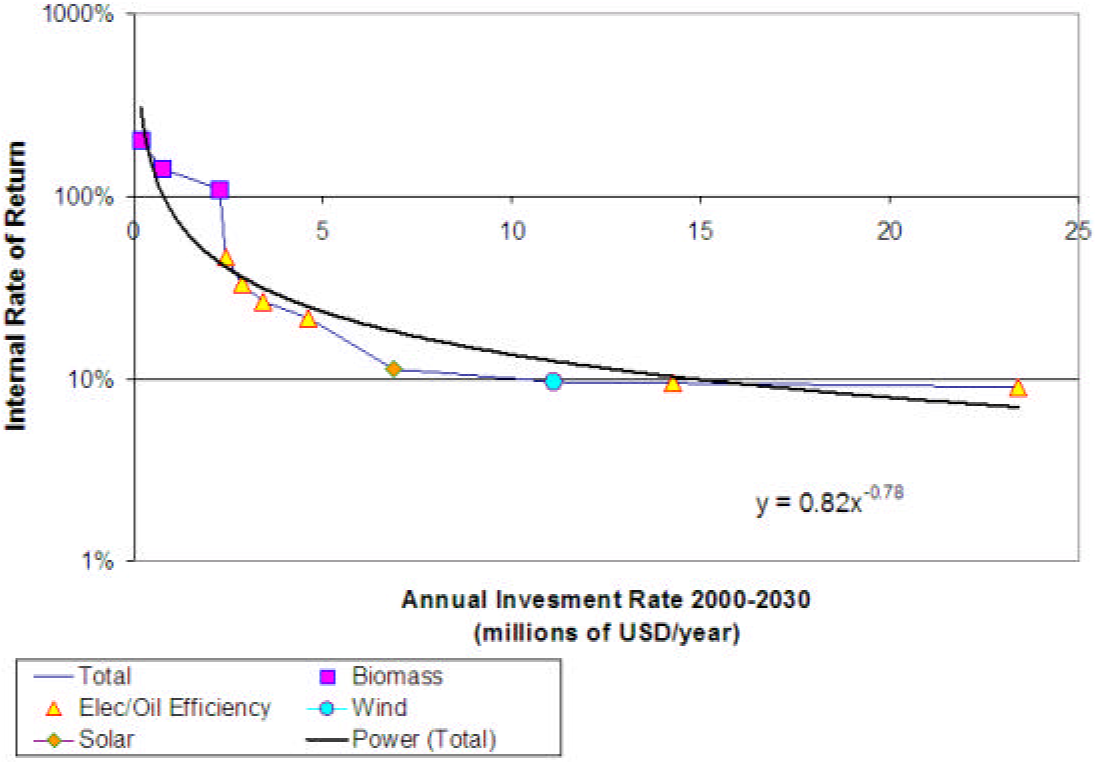
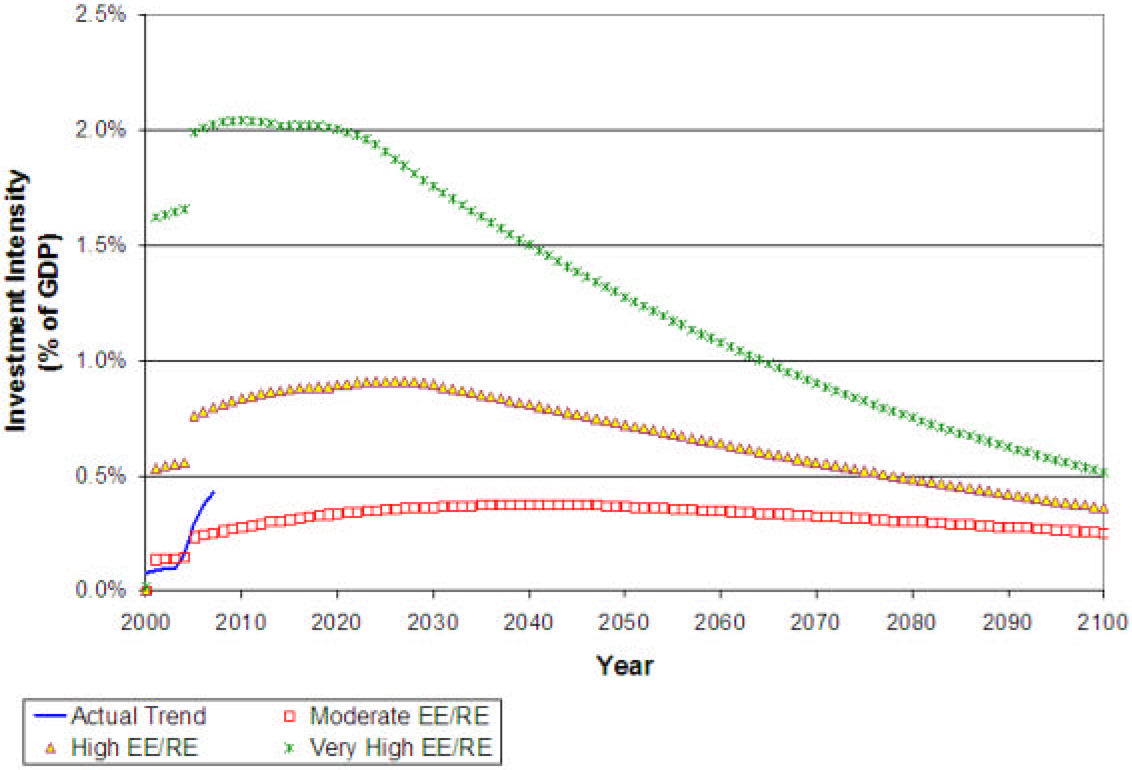

1000%
100%
10%
1%
Internal Rate of Return
0
5
10
15
20
25
y = 0.82x$^{-0.78}$
Annual Invesment Rate 2000-2030
(millions of USD/year)
Total
Biomass
Elec/Oil Efficiency
Wind
Solar
Power (Total)

Figure 7



2.5%
2.0%
1.5%
1.0%
0.5%
0.0%
Investment Intensity
(% of GDP)
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Year
Actual Trend
Moderate EE/RE
High EE/RE
Very High EE/RE

Figure 8

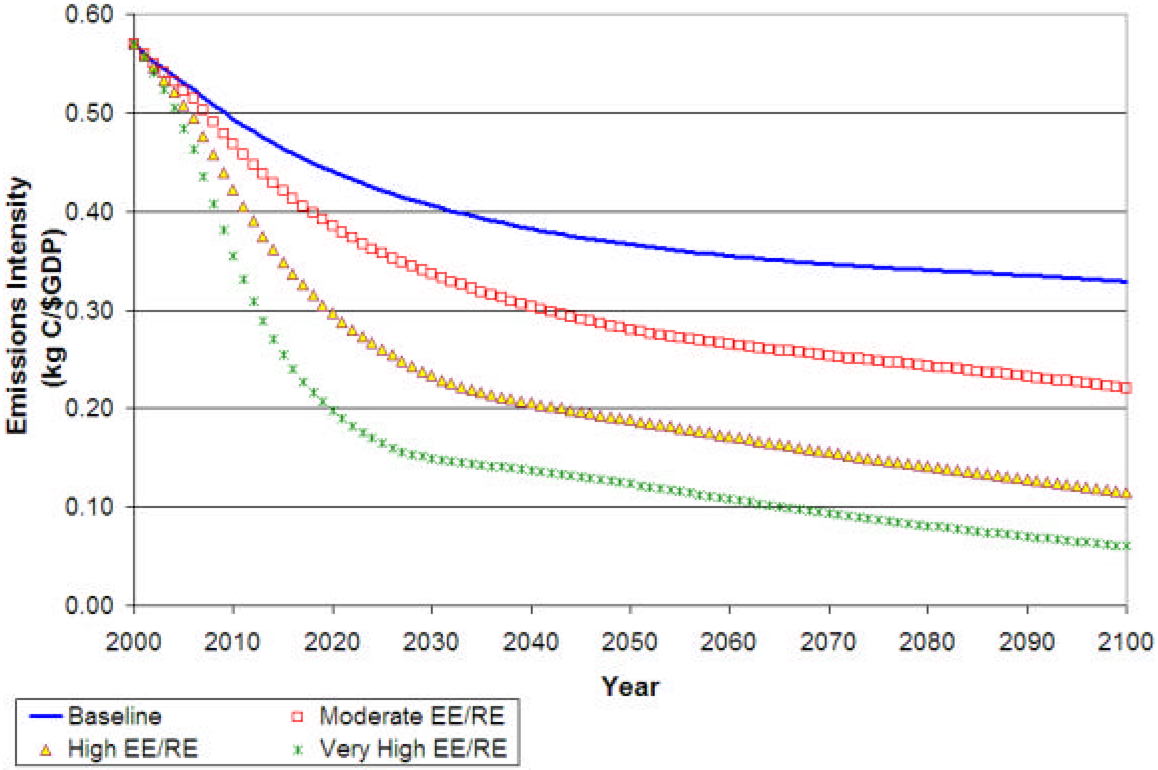
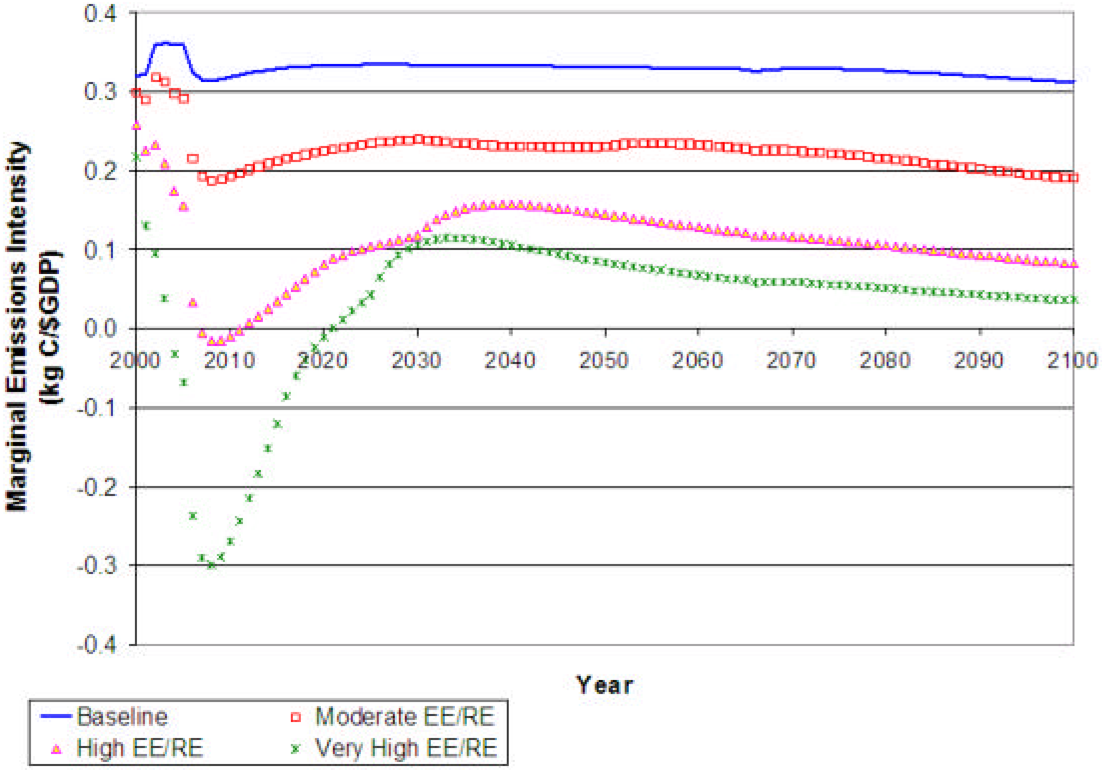

0.60
0.50
0.40
0.30
0.20
0.10
0.00
Emissions Intensity
(kg C/$GDP)
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Year
Baseline
Moderate EE/RE
High EE/RE
Very High EE/RE

Figure 9



0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Marginal Emissions Intensity (kg C/$GDP)
Year
Baseline
Moderate EE/RE
High EE/RE
Very High EE/RE