# Econ674

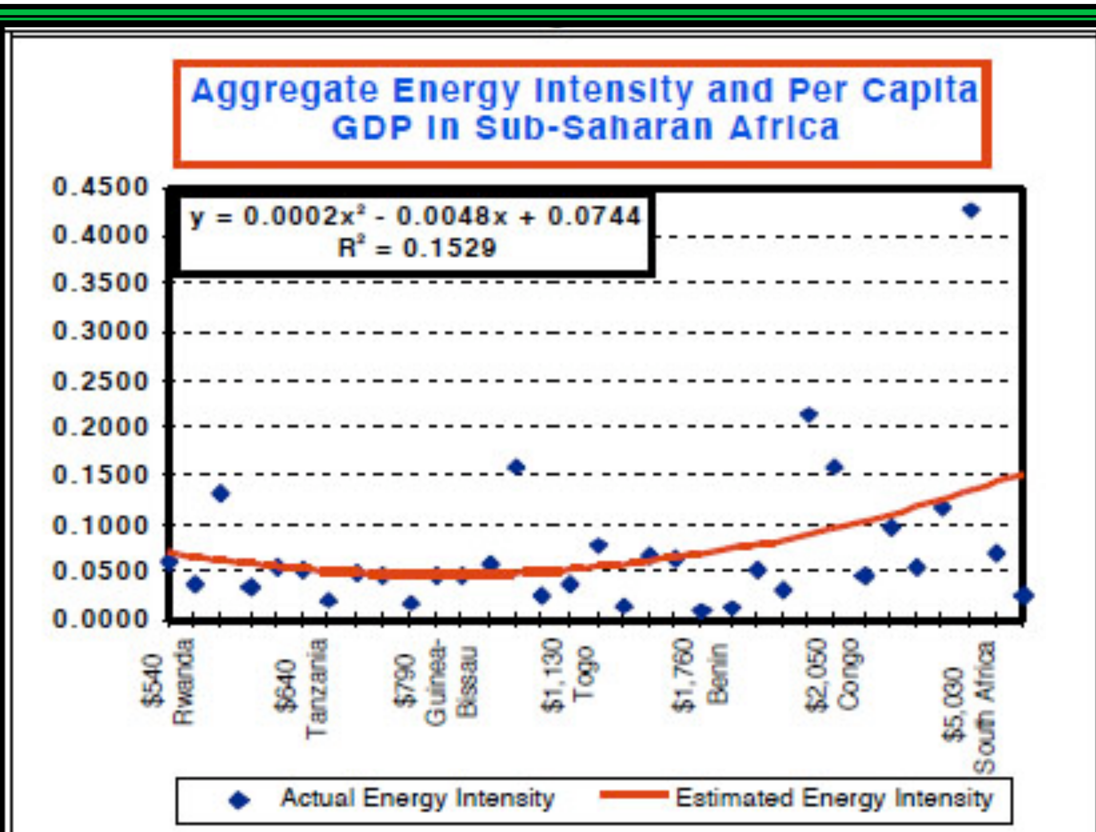
## Economics of Natural Resources and the Environment

## Session 14

Applications in Natural Resource Decisions

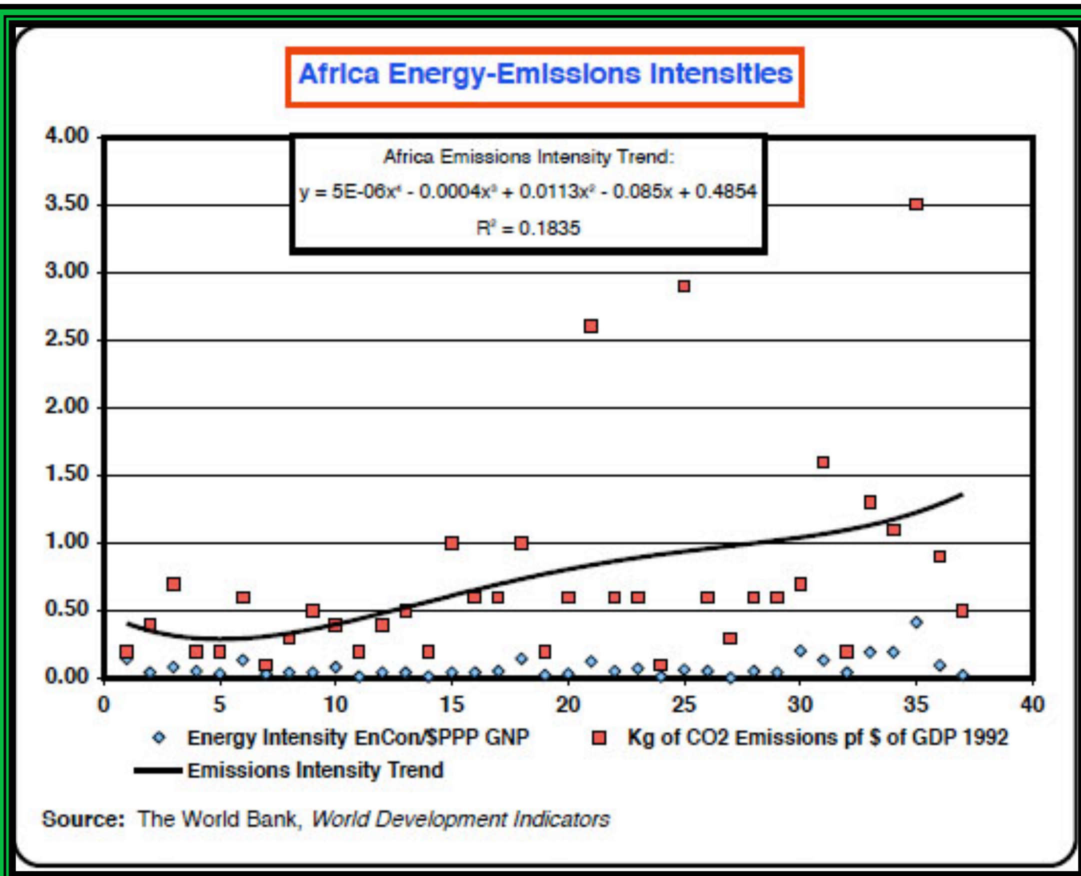
Crafting strategies for sustainable natural resource use involves the application of economically competitive natural resource materials and energy-using technologies in the economy. As we have seen, market prices may give a misleading framework for the adoption of sustainable choices, and may require the use of public sector intervention to correct for various forms of market failure. In this session, we draw on some research devoted to various aspects of natural resource use to illustrate how economic analysis can be used to shape public policy alternatives.

We begin with some data that characterize the use and impacts of natural resources in Ethiopia as well as some international comparisons on natural resource use and climate change. As shown below, using a cross-section of countries, Africa displays a predicted rise in aggregate energy intensity as urbanization proceeds and real per capita GDP levels increase




Source: The World Bank, *World Development Indicators*, 1997, and author's estimate.

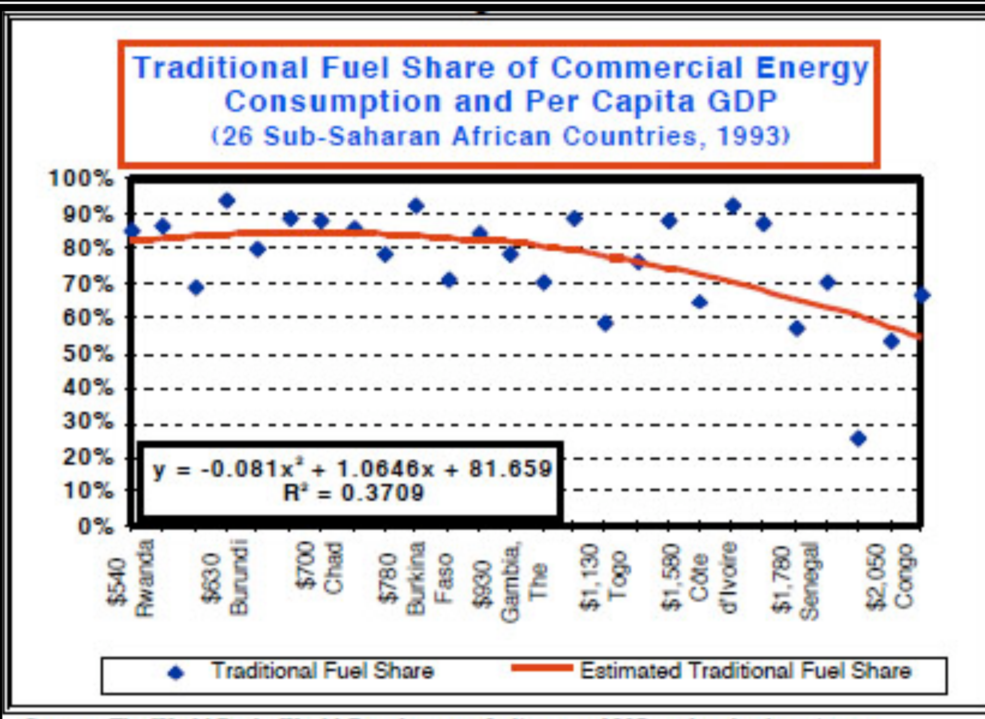
While energy intensities may fall as per capita incomes increase, given variable rates of depreciation for energy-using capital stocks, environmental emissions may increase at variable rates, thus posing risks to environmental sustainability and continued economic growth in the face of prospective climate change.




While environmental emissions in developing regions such as Africa do not begin to approach the levels found in industrialized countries, or in newly emerging economies such as China and India, adopting measures to contain emissions can have a significant impact on longer term growth prospects.

Much of the predicted shift in energy intensities and environmental emissions derives from a shift away from traditional renewable natural resources to exhaustible natural resources. However, this pattern is not foreordained except by the role of relative prices, and a shift to advanced renewable energy technologies may forestall some of the more adverse environmental impacts from a shift to traditional exhaustible energy and natural resource extraction technologies.

We can sense the risks of the natural resource shift in terms of the declining share of traditional wood energy in overall energy consumption in developing economies. The figure below illustrates how this transition has tended to occur in Sub-Saharan Africa.




Source: The World Bank, *World Development Indicators*, 1997, and author's estimate.

## Sustainable Growth Natural Capital Indicators in Sub-Saharan Africa

| | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| | GDP Annual Growth Rate 1990-95 | Population Growth Rate 1995-2010 | Annual Rate of Afforestation 1980-90 | Agricultural Productivity Annual Growth Rate | Natural Capital Productivity Growth Index(*) NCPGI=(a)*C+(1-a)*D | Per Capita Economic Growth Index PCEGI=A-B | Per Capita Natural Capital Productivity Index PCNCPI=E-D | Per Capita Sustainable Growth Index PCSGI=F+G |
| Rwanda | -12.80 | 3.50 | -0.20 | -0.1625 | -0.1719 | -16.3000 | -3.6719 | -19.9719 |
| Angola | -4.10 | 2.80 | -0.70 | 0.3323 | 0.0742 | -6.9000 | -2.7258 | -9.6258 |
| Sierra Leone | -4.20 | 2.70 | -0.60 | 0.4775 | 0.2081 | -6.9000 | -2.4919 | -9.3919 |
| Togo | -3.40 | 2.70 | -1.50 | 2.7400 | 1.6800 | -6.1000 | -1.0200 | -7.1200 |
| Cameroon | -1.80 | 2.90 | -0.60 | 1.7708 | 1.1781 | -4.7000 | -1.7219 | -6.4219 |
| Burundi | -2.30 | 2.50 | -0.60 | 1.4103 | 0.9077 | -4.8000 | -1.5923 | -6.3923 |
| Gabon | -2.50 | 2.30 | -0.60 | 1.8294 | 1.2221 | -4.8000 | -1.0779 | -5.8779 |
| Niger | 0.50 | 3.20 | -0.40 | 0.8533 | 0.5399 | -2.7000 | -2.6601 | -5.3601 |
| Congo | -0.60 | 2.60 | -0.20 | 1.7451 | 1.2588 | -3.2000 | -1.3412 | -4.5412 |
| Madagascar | 0.10 | 2.80 | -0.80 | 1.5798 | 0.9849 | -2.7000 | -1.8151 | -4.5151 |
| Zaire | -0.30 | 2.50 | -0.60 | 2.1202 | 1.4402 | -2.8000 | -1.0598 | -3.8598 |
| South Africa | 0.60 | 1.90 | 0.80 | -0.5262 | -0.1946 | -1.3000 | -2.0946 | -3.3946 |
| Zambia | -0.20 | 2.10 | -1.10 | 1.8427 | 1.1070 | -2.3000 | -0.9930 | -3.2930 |
| Malawi | 0.70 | 2.40 | -1.40 | 2.1228 | 1.2421 | -1.7000 | -1.1579 | -2.8579 |
| Zimbabwe | 1.00 | 1.60 | -0.70 | 0.0000 | -0.1750 | -0.6000 | -1.7750 | -2.3750 |
| Côte d'Ivoire | 0.70 | 2.20 | -1.00 | 2.8358 | 1.8769 | -1.5000 | -0.3231 | -1.8231 |
| CAR | 1.00 | 2.00 | -0.40 | 1.9364 | 1.3523 | -1.0000 | -0.6477 | -1.6477 |
| Mali | 2.50 | 3.00 | -0.80 | 2.9278 | 1.9959 | -0.5000 | -1.0041 | -1.5041 |
| Chad | 1.90 | 2.40 | -0.70 | 2.2804 | 1.5353 | -0.5000 | -0.8647 | -1.3647 |
| Namibia | 3.80 | 2.30 | -0.30 | -0.3040 | -0.3030 | 1.5000 | -2.6030 | -1.1030 |
| The Gambia | 1.60 | 2.10 | -0.80 | 2.4063 | 1.6047 | -0.5000 | -0.4953 | -0.9953 |
| Tanzania | 3.20 | 2.60 | -1.20 | 1.8681 | 1.1011 | 0.6000 | -1.4989 | -0.8989 |
| Kenya | 1.40 | 2.20 | -0.60 | 3.1830 | 2.2372 | -0.8000 | 0.0372 | -0.7628 |
| Guinea | 3.80 | 2.80 | -1.20 | 2.0291 | 1.2219 | 1.0000 | -1.5781 | -0.5781 |
| Senegal | 1.90 | 2.50 | -0.70 | 4.4889 | 3.1917 | -0.6000 | 0.6917 | 0.0917 |
| Mauritania | 4.00 | 2.30 | 0.00 | 0.9533 | 0.7150 | 1.7000 | -1.5850 | 0.1150 |
| Nigeria | 1.60 | 2.60 | -0.70 | 5.2809 | 3.7857 | -1.0000 | 1.1857 | 0.1857 |
| Burkina Faso | 2.60 | 2.70 | -0.70 | 4.9747 | 3.5560 | -0.1000 | 0.8560 | 0.7560 |
| Guinea-Bissau | 3.50 | 2.10 | -0.80 | 3.5461 | 2.4596 | 1.4000 | 0.3596 | 1.7596 |
| Mozambique | 7.10 | 2.40 | -0.80 | 0.1862 | -0.0603 | 4.7000 | -2.4603 | 2.2397 |
| Benin | 4.10 | 2.60 | -1.30 | 5.4676 | 3.7757 | 1.5000 | 1.1757 | 2.6757 |
| Botswana | 4.20 | 1.70 | -0.50 | 2.7712 | 1.9534 | 2.5000 | 0.2534 | 2.7534 |
| Ghana | 4.30 | 2.40 | -1.40 | 4.8696 | 3.3022 | 1.9000 | 0.9022 | 2.8022 |
| Sudan | 6.80 | 2.20 | -1.10 | 1.3106 | 0.7079 | 4.6000 | -1.4921 | 3.1079 |
| Uganda | 6.60 | 2.60 | -1.00 | 3.6840 | 2.5130 | 4.0000 | -0.0870 | 3.9130 |
| Mauritius | 4.90 | 1.00 | -0.20 | 2.0659 | 1.4994 | 3.9000 | 0.4994 | 4.3994 |
| Ethiopia | 2.40 | 2.80 | -0.30 | n/a | n/a | -0.4000 | n/a | n/a |

Source: The World Bank, *World Development Indicators 1997*.

(*) Natural capital productivity growth index weights: 0.25 for forestry productivity, 0.75 for agricultural productivity. Weights should be based on the economic value of the capitalized asset. Since such a measure is not readily available, these weights should be considered as illustrative.

Ethiopia is typical in its reliance on traditional wood energy for much of its consumption of energy. As per capita income increases, there is growing demand for traditional wood resources, and which also results in an increase in the demand for electrical energy. Ethiopia has, however, significant hydropower potential that can meet the future growth of electricity demand for some time.

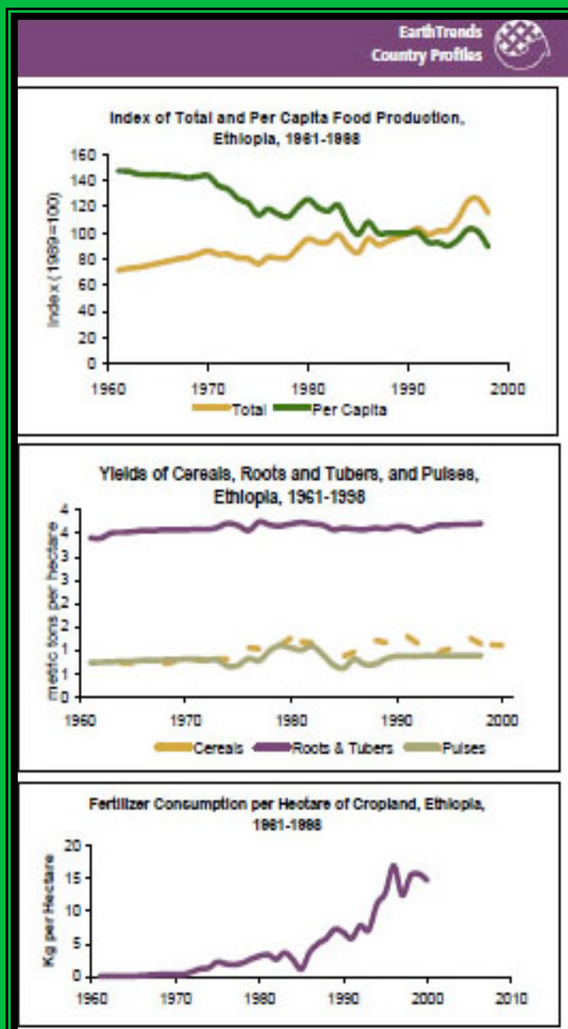
## Energy and Resources-- Ethiopia

| Energy Production and Consumption (in thousand metric tons of oil equivalent) {a} | Ethiopia | Sub-Saharan Africa | World |
|---|---|---|---|
| Total energy production, 2000 | 17,583 | 552,808 | 10,077,984 |
| % change since 1980 | 66% | 71% | 37% |
| Energy imports, 1997 | 962 | 28,564 | 9,521,506 |
| Energy exports, 1997 | 79 | 219,173 | 3,419,104 |
| Total energy consumption {b}, 1999 | 18,227 | X | 9,702,786 |
| Electricity consumption, 1999 | 116 | X | 1,040,770 |
| Energy consumption per capita, 1997 | 0.29 | 0.54 | 1.64 |
| % change since 1990 | -9% | -2% | 0% |
| Energy consumption per GDP {c}, 1999: | 477 | 425 | 244 |
| % change since 1990 | -12% | 4% | -13% |
| **Energy Consumption by Source, 1999 (in thousand metric tons oil equivalent)** | | | |
| Total Fossil Fuels | 1,052 | X | 7,689,047 |
| Coal and coal products | 0 | X | 2,278,524 |
| Crude oil and natural gas liquids | 0 | X | 3,563,084 |
| Natural gas | 0 | X | 2,012,559 |
| Nuclear | 0 | X | 661,901 |
| Hydroelectric | 138 | X | 222,223 |
| Renewables, excluding hydroelectric: | 17,038 | X | 1,097,889 |
| Primary solid biomass (includes fuelwood) | 17,016 | X | 1,035,139 |
| Biogas and liquid biomass | 0 | X | 14,931 |
| Geothermal | 22.4 | X | 43,802 |
| Solar | 0.0 | X | 2,217 |
| Wind | 0.0 | X | 1,748 |
| Tide, wave, and ocean | 0.0 | X | 53 |
| **Energy Consumption by Sector, 1999 (in thousand metric tons of oil equivalent)** | | | |
| Industry | 274 | X | 2,140,474 |
| Transportation | 609 | X | 1,755,505 |
| Agriculture | 0 | X | 166,287 |
| Commercial & public services | 26 | X | 511,555 |
| Residential | 344 | X | 1,845,475 |
| Non-energy uses and "other" consumption | 16,286 | X | 333,981 |
| Total final energy consumption {d} | 17,539 | X | 6,753,276 |

Ethiopia's natural resource production and consumption consists of agricultural activity, along with the extraction of energy and materials from natural resources, notably forestry and hydropower. Erratic rainfall patterns, along with relatively low levels of per capita GDP, leave substantial parts of the population vulnerable to food shortages as long as productivity rates do not match population growth rates.

## Agriculture and Food-- Ethiopia

| Agricultural Production and Yields | Ethiopia | Sub-Saharan Africa | World |
|---|---|---|---|
| Cereals, 1999-2001 | | | |
| Average production (000 metric tons) | 8,812 | 87,715 | 2,075,387 |
| Percent change since 1979-81 | 54% | 54% | 32% |
| Per capita production (tons per person) | 140 | 135 | 343 |
| Percent change since 1979-81 | -14% | -11% | -4% |
| Average crop yield (kg per ha) | 1,164 | 1,221 | 3,096 |
| Percent change since 1979-81 | -2% | 9% | 41% |
| Roots and tubers 1996-1998 | | | |
| Average production (000 metric tons) | 2,058 | 132,744 | 638,438 |
| Average crop yield (kg per ha) | 3,704 | 7,694 | 12,958 |
| Pulses, 1996-1998 | | | |
| Average production (000 metric tons) | 1,145 | 6,499 | 55,469 |
| Average crop yield (kg per ha) | 894 | 481 | 808 |
| Meat, 1999-2001 | | | |
| Average production (000 metric tons) | 650 | 8,124 | 233,218 |
| Percent change since 1979-81 | 23% | 49% | 71% |
| **Agricultural Land,** | | | |
| Total cropland (000 ha), 1999 | 10,728 | 173,572 | 1,501,452 |
| Hectares of cropland per 1,000 population, 1999 | 175 | 274 | 251 |
| Arable & permanent cropland as a percent of total land area, 1998 | 9.6% | 7.1% | 11.3% |
| Percent of cropland that is irrigated, 1999 | 1.8% | 3.8% | 18.3% |
| **Agricultural Inputs** | | | |
| Average annual fertilizer use, 1999 | | | |
| Total (thousand metric tons) | 168 | 2,124 | 141,360 |
| Intensity (kg per hectare cropland) | 16 | 12 | 94 |
| Pesticide use, 1994-1996 (kg/ha cropland) {c} | 34 | X | X |
| Number of tractors, 1997 | 3,000 | 261,984 | 26,334,690 |
| Agricultural workers as a percentage of the total labor force, 1990 | 86.2% | X | X |
| Percent of GDP generated from agricultural activities, 2000 | 52.3% | 16.7% | 5.0% |



Climate variation in Ethiopia places periodic stress on the food production and distribution system. Much of this stems from erratic rainfall patterns that produce periodic droughts. Moreoever, while rainfall cycles vary, there is a long-term secular trend that reflects in part the impact of global climate change. Without changes in agricultural technology, rainfed agriculture may face limits as to how to maintain productivity growth in the face of expanding population levels.

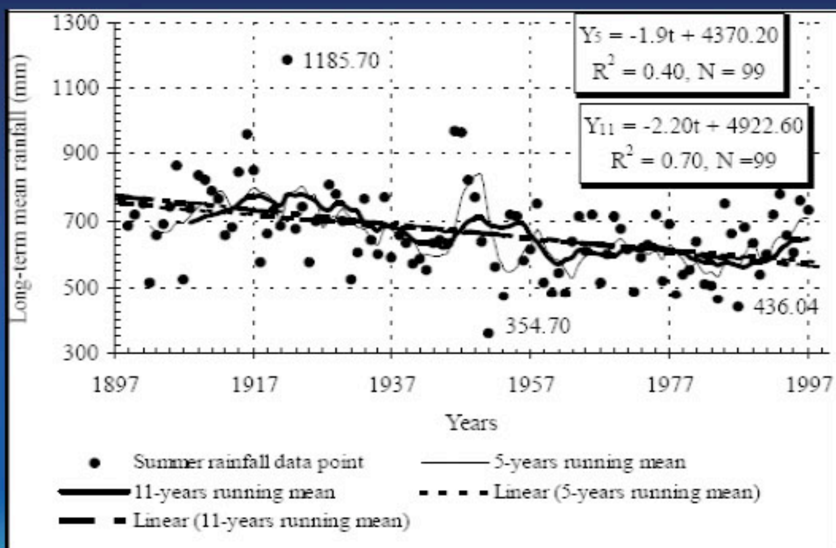



**Figure: Long-term summer rainfall time series of the central highlands of Ethiopia (1898-1997)**

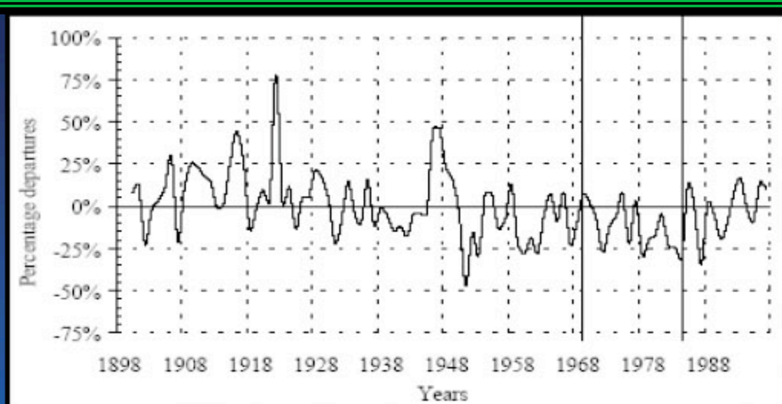



**Figure: Departure of long-term summer rainfall from its long-term average in the central Ethiopian highlands**

- **The positive departures observed during the first half of the 20th century are highly pronounced in the first three decades**
- **The second half of the 20th century suffered predominantly negative rainfall deviations, with summer values frequently lower than the long-term average**

Climatologists, using historical data, have derived frequency estimates of past drought episodes in Ethiopia and from which, other things equal, future drought episodes are predicted.

## *The Frequency of Drought in Ethiopia*

| Year interval | Number of disasters | Average recurrence |
|---|---|---|
| Average recurrence | 5 | Once in 40 years |
| 12AD-787AD | 6 | Roughly once in 100 years |
| 832AD-968AD | 3 | Roughly once in 45 years |
| 1006AD-1200AD | 4 | Roughly once in 48 years |
| 1252-1340 | 5 | Roughly once in 18 years |
| 1400-1789 | 26 | Roughly once in 15 years |
| 1800-1900 | 10 | Roughly once in 10 years |
| 1900-1987 | 14 | Roughly once in 6 years |
| 1988-2002 | 5 | Roughly once in 3 years |

Table: Frequency of occurrences of drought events in Ethiopia (Source: NMSA, 1987)

## *Records of Natural Disasters, and Climate Change Related Extremes*

Table 3.7.2. Top 10 Natural Disasters in Ethiopia sorted by total number of people affected

| Disaster | Date | Total Affected |
|---|---|---|
| Drought | 2003 | 12,600,000 |
| Drought | May-1983 | 7,750,000 |
| Drought | Jun-1987 | 7,000,000 |
| Drought | Oct-1989 | 6,500,000 |
| Drought | Dec-1973 | 3,000,000 |
| Drought | Nov-2005 | 2,600,000 |
| Drought | Sep-1969 | 1,700,000 |
| Drought | Jul-1965 | 1,500,000 |
| Drought | Feb-1997 | 986,200 |
| Flood | 27-Oct-2006 | 361,600 |

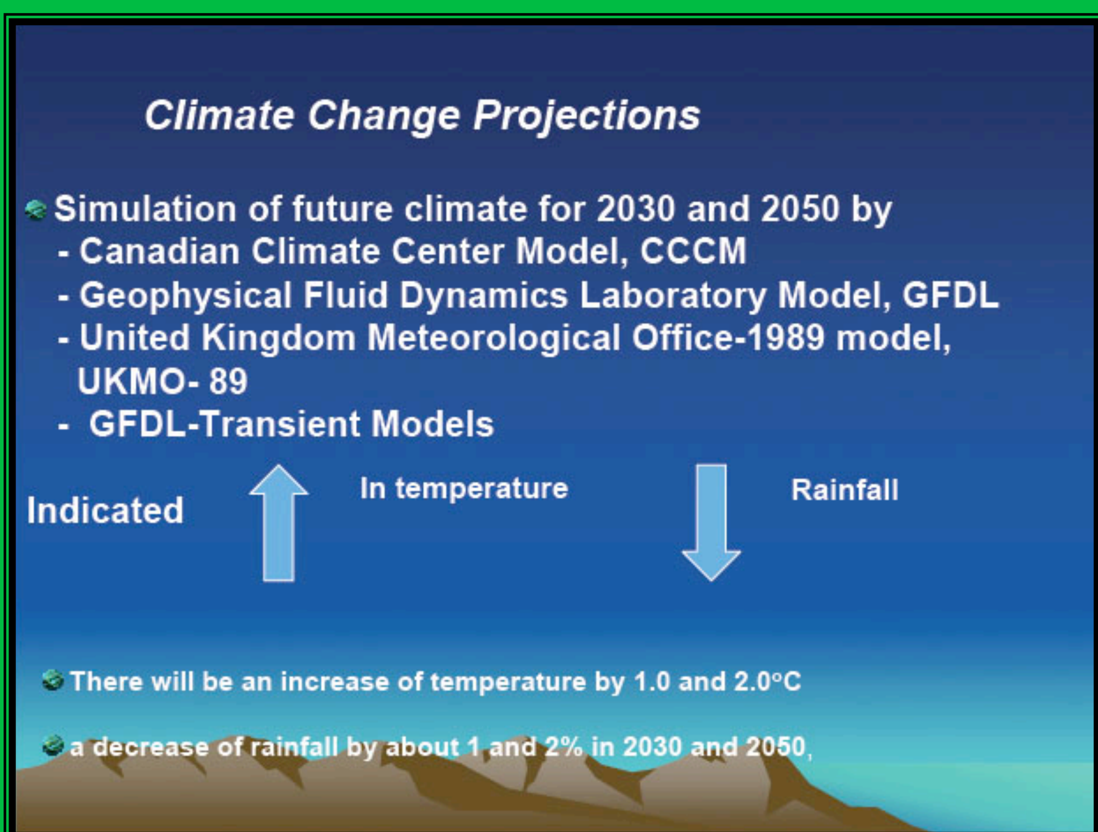
Source: "EM-DAT: The OFDA/CRED International Disaster Database, [illegible]

Natural disasters can be costly, not just in terms of today's economic environment, but also in terms of prospective future events.


Table: Top 10 Natural Disasters in Ethiopia sorted by economic damage costs

| Disaster | Date | Damage US$ (000's) |
|---|---|---|
| Drought | Dec-1973 | 76,000 |
| Drought | Jul-1998 | 15,600 |
| Earthquake | 25-Aug-1906 | 6,750 |
| Flood | 23-Apr-2005 | 5,000 |
| Flood | 15-Aug-1994 | 3,500 |
| Flood | 5-Aug-2006 | 3,200 |
| Flood | 20-May-2005 | 1,200 |
| Drought | Sep-1969 | 1,000 |
| Flood | 7-May-1968 | 920 |
| Earthquake | 29-Mar-1969 | 320 |

Source: "EM-DAT: The OFDA/CRED International Disaster Database, www.em-dat.net



Managing natural resources in a sustainable pattern must address not only agricultural production and consumption, but also alternative technologies that can permit sustainable economic growth. To do so requires an economic perspective on the pricing of natural resources and on the technologies that use them in the economy.

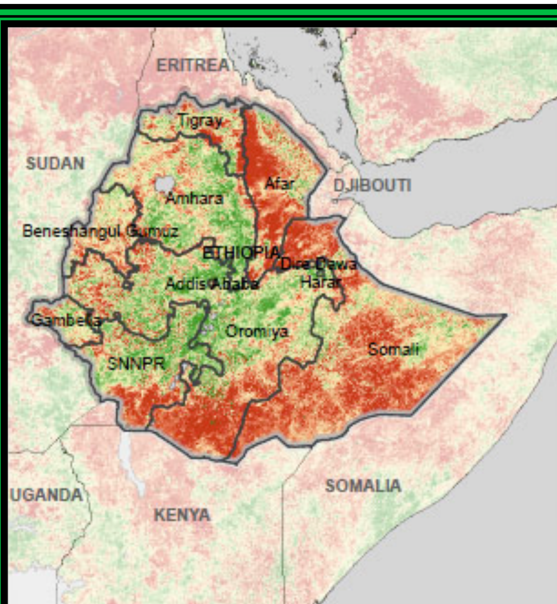



Figure 1. Vegetation Index of August 2008 in relation to the historical maximum and minimum values of the period 1999 to 2007

Table 4 Percentage distribution of households by domestic expenditure categories at country, rural and urban area levels by survey year

| Level | Domestic Expenditure in Birr per Household per annum | | | | | |
|---|---|---|---|---|---|---|
| | *Less than 2000* | | *2000-12599* | | *12600 or more* | |
| | *1995/96* | *1999/2000* | *1995/96* | *1999/2000* | *1995/96* | *1999/2000* |
| Country | 9.7 | 8.0 | 86.9 | 87.8 | 3.4 | 4.1 |
| Rural | 10.0 | 8.0 | 88.4 | 89.4 | 1.7 | 2.6 |
| Urban | 8.5 | 7.4 | 78.5 | 79.2 | 13.0 | 13.3 |

Source: CSA Household Consumption and Expenditure Survey of 1999/2000.

Annex table 1 Core food security and nutrition indicators for Ethiopia

| Indicators | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | Average |
|---|---|---|---|---|---|---|---|---|
| Dietary calorie supply per person (cal/cap/day) | 1656 | 1686 | 1830 | 1799 | 1759 | 1851 | 2023 | 1800 |
| Cereals, roots and tubers as a % of dietary calorie supply | | | 80% | 81% | 81% | 80% | 82% | 81 % |
| Life expectancy at birth, total (years) | | | .. | 43.3 | .. | 42.4 | 42.3 | 42.7 |
| Mortality rate, under-5 (per 1,000 live births) | | | .. | 166.2 | .. | .. | 178.9 | 172.6 |
| Malnutrition, weight for age (% of under 5 that are underweight) | | .. | .. | .. | .. | .. | 47.2 | 47.2 |
| Malnutrition, height for age (% of under 5 that are stunted) | .. | .. | .. | .. | .. | .. | 51.4 | 51.4 |
| Food Availability | | | | | | | | |
| Animal protein supply (gr/cap/day) | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| Cereals supply per person (kg/cap/yr) | 123 | 122 | 135 | 134 | 132 | 138 | 158 | 135 |
| Dietary fat supply gr/cap/day | 20 | 19 | 21 | 19 | 19 | 20 | 21 | 20 |
| Dietary protein gr/cap/day | 47 | 50 | 54 | 53 | 51 | 54 | 60 | 53 |

Souce: FAO FIVIMS indicators.

For agriculture, it means forecasting production and consumption patterns consistent with various estimates of population growth, and from which food shortfalls may arise. Those shortfalls can be met in the short term by imported food aid, but over the long run, the question is whether Ethiopia can increase productivity to levels that would sustain domestic consumption patterns consistent with global nutritional standards such as those put forth by FAO and other agencies.

**Annex table 4 Regression estimate of determinants of household income in rural areas**

| Explanatory variables | Unstandardized Coefficients B | Unstandardized Coefficients Std. Error | Stand. Coeffi. Beta | t | Sig. |
|---|---|---|---|---|---|
| Constant | -2625 | 787.99 | | -3.331 | .001 |
| Educational grade of household head | 85.683 | 30.242 | .058 | 2.833 | .005 |
| Total farm input cost (birr) | 3.823 | .218 | .500 | 17.515 | .000 |
| Total cultivated land (ha) | 401.23 | 84.876 | .120 | 4.727 | .000 |
| Distance to input supply (minutes) | -3.944 | 1.514 | -.050 | -2.605 | .009 |
| Land quality index | 801.97 | 315.050 | .051 | 2.546 | .011 |
| Number of oxen owned (No) | 232.48 | 73.73 | .075 | 3.153 | .002 |
| Rainfall sufficiency index | 44782 | 876.30 | .100 | 5.110 | .000 |
| Household labor force (ME) | 203 | 52.86 | .077 | 3.84 | .000 |
| Age of household head (year) | -1.01 | 4.77 | -.004 | -.211 | .833 |
| Sex of head (1= male) | 14.65 | 175.65 | .002 | .083 | .934 |
| Region dummy, Tigray | 503 | 292 | .039 | 1.724 | .085 |
| Region dummy, Oromiya | 877 | 192.30 | .116 | 4.561 | .000 |
| Region dummy, SNNP | -37 | 230.88 | -.004 | -.159 | .873 |
| Fertilizer used (kg) | 3.32 | .96 | .106 | 3.447 | .001 |
| Labor input in farming (MD/ha) | .570 | .327 | .035 | 1.740 | .082 |

Y = Total household income (birr); F = 120.921 and significant at 1% probability level. R2 adj = .57; N = 1322.
Source: Authors' calculations.

**Table 6 Estimates of income elasticity of food expenditure and nutrient intake by income source and income groups**

| Location and measures | *All* Food exp | *All* calorie | *All* protein | *All* fat | Income group *1st quartile* Food exp | *1st quartile* calorie | *1st quartile* protein | *1st quartile* fat | *2nd Quartile* Food exp | *2nd Quartile* calorie | *2nd Quartile* protein | *2nd Quartile* fat |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rural Elasticity and t-value | 0.57* (11.2) | 0.62* (11.7) | 0.67* (12.9) | 0.61* (8.4) | 0.64* (6.1) | 0.50* (4.5) | 0.57* (5.4) | 0.28** (1.8) | 0.58* (7.4) | 0.54* (6.5) | 0.57* (6.9) | 0.44* (3.9) |
| Model, R2 | 0.40 | 0.46 | 0.48 | 0.37 | 0.53 | 0.55 | 0.54 | 0.46 | 0.44 | 0.48 | 0.48 | 0.42 |
| Urban Elasticity and t- value | 0.57* (38.8) | 0.33* (16.9) | 0.35* (17.9) | 0.42* (17.6) | 0.98* (42.9) | 0.76* (9.1) | 0.86* (10.9) | 0.84* (7.82) | 0.96* (60.7) | 0.61* (13.4) | 0.70* (15.7) | 0.70* (12.4) |
| Model, R2 | 0.76 | 0.39 | 0.43 | 0.47 | 0.94 | 0.47 | 0.53 | 0.39 | 0.93 | 0.44 | 0.50 | 0.43 |

Food import dependence from erratic rainfall and agricultural yields poses problematic questions regarding the economic efficiency and equity of using agricultural subsidies.

Table 2: Estimated welfare gain from subsidy and reduced food import dependence

| | Price subsidy (% increase in average price) | | | |
|---|---|---|---|---|
| | 10 | 20 | 30 | 40 |
| Total food requirement (tons)* | 15554250 | 15554250 | 15554250 | 15554250 |
| Domestic prod (livestock + others) (ton) | 1975000 | 1975000 | 1975000 | 1975000 |
| Domestic prod. Grain (tones) | 7881571 | 7881571 | 7881571 | 7881571 |
| Dom. net grain (allow 15% seed and loss) (ton) | 6699335 | 6699335 | 6699335 | 6699335 |
| Domestic prod (crop + others) (ton) | 8674335 | 8674335 | 8674335 | 8674335 |
| Food aid, average (ton) | 800,000 | 800,000 | 800,000 | 800,000 |
| Total supply (domestic + aid), ton | 9,474,335 | 9,474,335 | 9,474,335 | 9,474,335 |
| Desired food import (demand minus supply) | 6,079,915 | 6,079,915 | 6,079,915 | 6,079,915 |
| Cultivated area for cereals (ha) | 7286850 | 7286850 | 7286850 | 7286850 |
| Area elasticity wrt cereals price, short-run** | 0.380 | 0.380 | 0.380 | 0.380 |
| Average yield of cereals, tons/ha | 1.1 | 1.1 | 1.1 | 1.1 |
| Subsidy (rise in cereal price, assumed), % | 10 | 20 | 30 | 40 |
| Current cereal price (avr. 1995-2000) birr/ton | 1,500 | 1,500 | 1,500 | 1,500 |
| Grain price including subsidy (birr/ton) | 1,650 | 1,800 | 1,950 | 2,100 |
| Price subsidy (birr/ton) | 150 | 300 | 450 | 600 |
| Increased area of cereals due to subsidy (%) | 3.8 | 7.6 | 11.4 | 15.2 |
| Net increment (allow 15% seed and loss) (ton) | 258,902 | 517,804 | 776,705 | 1,035,607 |
| New level of doms. food supply with subsidy | 8,933,237 | 9,192,139 | 9,451,041 | 9,709,942 |
| Food supply (dom + aid) (ton), with subsidy | 9,733,237 | 9,992,139 | 10,251,041 | 10,509,942 |
| New desired level of import (tones) | 5,821,013 | 5,562,111 | 5,303,209 | 5,044,308 |
| Reduction in import demand (%) | 4.3 | 8.5 | 12.8 | 17.0 |
| Welfare gain (0.5 x subs x Δ prod) (birr) | 19,417,634 | 77,670,534 | 174,758,702 | 310,682,137 |
| Area of cereals fertilized (40%), hectare *** | 110,760 | 221,520 | 332,280 | 443,040 |
| Incre.. yield from fertilizer in cereals (ton/ha) | 0.83 | 0.83 | 0.83 | 0.83 |
| Incre. Prod. use of fertilizer (ton) | 78,141 | 156,283 | 234,424 | 312,565 |
| Food supply (dom. + aid) (ton), sub + fertilizer | 9811378 | 10148421 | 10485464 | 10822507 |
| Total incr. prod (ton), with sub. + fertilizer | 337043 | 674086 | 1011129 | 1348172 |
| Import demand with subsidy + fertilizer (tone) | 5742872 | 5405829 | 5068786 | 4731743 |
| Reduced import demand (%) | 6 | 11 | 17 | 22 |
| Welfare gain (0.5 x subs x Δ prod) (birr) | 25278228 | 101112914 | 227504055 | 404451654 |

* Food demand is estimated based on per capita food requirement (225 kg) estimated based on 2100 kcal/person/day, and the current Ethiopian population of 69.13 million. ** Elasticity coeff. 0.38 for maize (short run), and also 0.38 (long run), average for major cereal crops. *** Currently, 40% of the total cultivated area, mainly of cereal, is fertilized.

**Table 2:** Fertilizer use in the Highlands of Ethiopia, 2002-2007

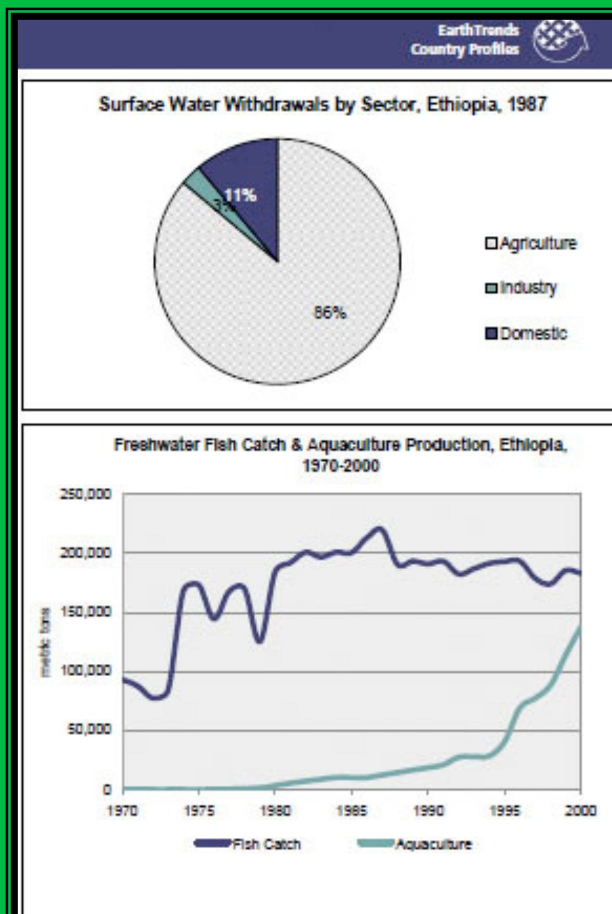
| Year | Farmers using fertilizer (%) | | Application rate per ha (kg) | |
|---|---|---|---|---|
| | Plot-Level | Farm-Level | Plot-level | Farm-Level |
| 2002 | 23.68 | 53.05 | 42.092 | 35.123 |
| 2004 | 18.46 | 36.65 | 51.3889 | 69.269 |
| 2007 | 17.45 | 30.57 | 348.7999 | 89.769 |

*Source: Authors' own calculation.*

In addition to agriculture, sustainable use of natural resources also involves the adoption of economically competitive technologies that can mitigate the environmental emissions effects from significant shifts to exhaustible fossil fuels as well as to provide sufficient end use natural resources that can support sustainable economic growth. For a country such as Ethiopia, this means looking at the extent to which hydro, wind, and geothermal natural resources, for example, can provide sufficient levels of energy to permit sustainable increases in per capita real GDP.

## Water Resources and Freshwater Ecosystems-- Ethiopia

| | Ethiopia | Sub-Saharan Africa |
|---|---|---|
| **Internal Renewable Water Resources (IRWR),1977-2001, in cubic km** | | |
| Surface water produced internally | 110 | 3,812 |
| Groundwater recharge | 40 | 1,549 |
| Overlap (shared by groundwater and surface water) | 40 | 1,468 |
| Total internal renewable water resources (surface water + groundwater - overlap) | 110 | 3,901 |
| Per capita IRWR, 2001 (cubic meters) | 1,666 | 5,705 |
| **Natural Renewable Water Resources (includes flows from other countries)** | | |
| Total, 1977-2001 (cubic km) | 110 | X |
| Per capita, 2002 (cubic meters per person) | 1,666 | X |
| Annual river flows: | | |
| From other countries (cubic km) | 0 | X |
| To other countries (cubic km) | X | X |
| **Water Withdrawals** | | |
| Year of withdrawal data | 1987 | |
| Total withdrawals (cubic km) | 2.2 | X |
| Withdrawals per capita (cubic m) | 51 | X |
| Withdrawals as a percentage of actual renewable water resources | 3.1% | X |
| Withdrawals by sector (as a percent of total) {a} | | |
| Agriculture | 86% | X |
| Industry | 3% | X |
| Domestic | 11% | X |
| **Desalination (various years)** | | |
| Desalinated water production (million $m^3$) | 0 | X |
| **Freshwater Fish Species, 1990s** | | |
| Total number of species | 150 | X |
| Number of threatened species | 0 | X |



Beyond water for use in agriculture, by consumption of potable supplies in the general population, and by fishing, water also can be used to generate electricity. Ethiopia's hydropower potential is indicated in the following datasets.

**Table 2 Hydropower Potential of Ethiopia**

| Name of River Basin | Number of Potential Sites | | | | | |
|---|---|---|---|---|---|---|
| | Small Scale 40 MW | Medium Scale 40-60 MW | Large Scale > 60 MW | Total | Technical Hydropower Potential (GWh/year) | Percentage Share of the Total % |
| Abbay | 74 | 11 | 44 | 129 | 78,800 | 48.9 |
| Rift Valley Lakes | 7 | - | 1 | 8 | 800 | 0.5 |
| Awas | 33 | 2 | - | 35 | 4,500 | 2.8 |
| Omo – Gibe | 4 | - | 16 | 20 | 35,000 | 22.7 |
| Genale – Dawa | 18 | 4 | 9 | 31 | 9,300 | 5.8 |
| Wabi Shebelle | 9 | 4 | 3 | 16 | 5,400 | 3.4 |
| Baro Akabo | 17 | 3 | 21 | 41 | 18,900 | 11.7 |
| Tekeze – Angereb | 11 | 1 | 8 | 20 | 6,000 | 4.2 |
| **Total** | **173** | **25** | **100** | **300** | **159,300** | |

## Table 3 Development of Hydropower in Ethiopia

| Name of Hydropower Scheme | Year of Commissioning G.C. | Installed Capacity (MW) | Energy Production GWh/Year Energy | |
|---|---|---|---|---|
| | | | Average | Firm |
| Aba Samuel* | 1932 | 6 | 1.5 | - |
| TisAbay | 1953 | 11.5 | 68 | 55 |
| Koka | 1960 | 43.2 | 110 | 80 |
| Awash II | 1966 | 32 | 165 | 120 |
| Awash III | 1971 | 32 | 165 | 120 |
| Fincha | 1973 | 100 | 617 | 613 |
| Melka Wakena | 1989 | 153 | 560 | 440 |
| Sor | 1990 | 5 | 60 | 48 |
| Smaller Stations | | 1.15 | 5 | 4 |
| | | | 1,705 | 1480 |

* Inoperative since 1970.

**Table 1. Hydropower Plants and Installed Capacity**

| Plant | System | Installed Capacity MW | Guaranteed Capacity MW | Energy Generation in GWH/year | Year of Commission |
|---|---|---|---|---|---|
| Finchaa HPP | ICS | 100 | 100 | 616 | 1973 |
| MelkaWakena HPP | ICS | 153 | 148 | 434 | 1988 |
| AwashII HPP | ICS | 32 | 26 | 135 | 1966 |
| AwashLII HPP | ICS | 32 | 32 | 135 | 1974 |
| Koka HPP | LCS | 43.2 | 25 | 70 | 1960 |
| TisAbbay I HPP | ICS | 11.4 | 3.8 | 27 | 1964 |
| **Total ICS** | | **371.6** | **334.8** | **1,417** | |
| Yadot HPD | SCS | 0.35 | 0.3,5 | 1.2 | 1990 |
| Sor HPP | SCS | 5 | 5 | 48 | 1990 |
| Dembi HPP | SCS | 0.8 | 0.8 | 2.8 | 1991 |
| **Total SCS** | | **6.15** | **6.15** | **52** | |
| **Grand Total** | | **377.75** | **340.95** | **1,469** | |

One major effort to develop hydropower is the Blue Nile plan. Details of this plan are spelled out below.

**Figure 2. Proposed hydroelectric dams along the Blue Nile in plan view, as proposed by the USBR**

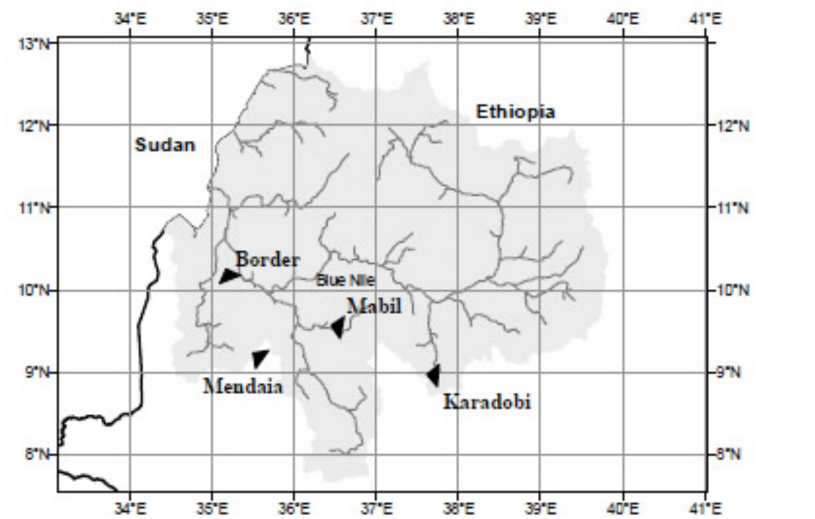


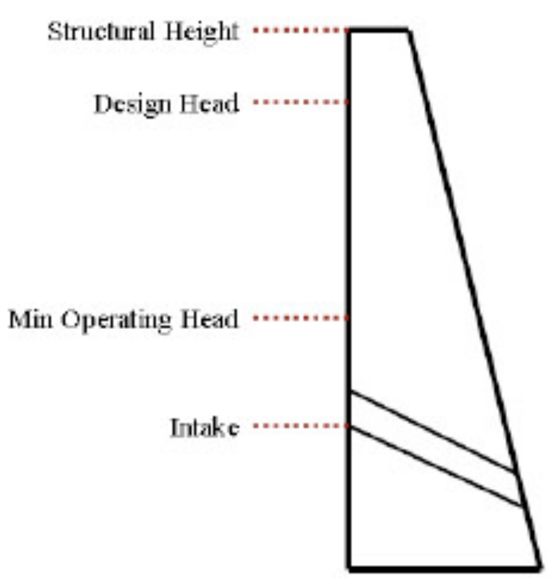

**Table 1. Proposed dam characteristics.**

| Project Name | Structural Height (m) | Crest Length (m) | Design Head (m) | Min. Oper. Head (m) | Intake (m) |
|---|---|---|---|---|---|
| Karadobi | 252 | 980 | 181.4 | 116 | 102.5 |
| Mabil | 171 | 856 | 113.6 | 73.8 | 59.7 |
| Mendaia | 164 | 1134 | 117.4 | 109.8 | 70.4 |
| Border | 84.5 | 1200 | 75 | 68.4 | 27.8 |

**Table 2. Proposed reservoir and power characteristics.**

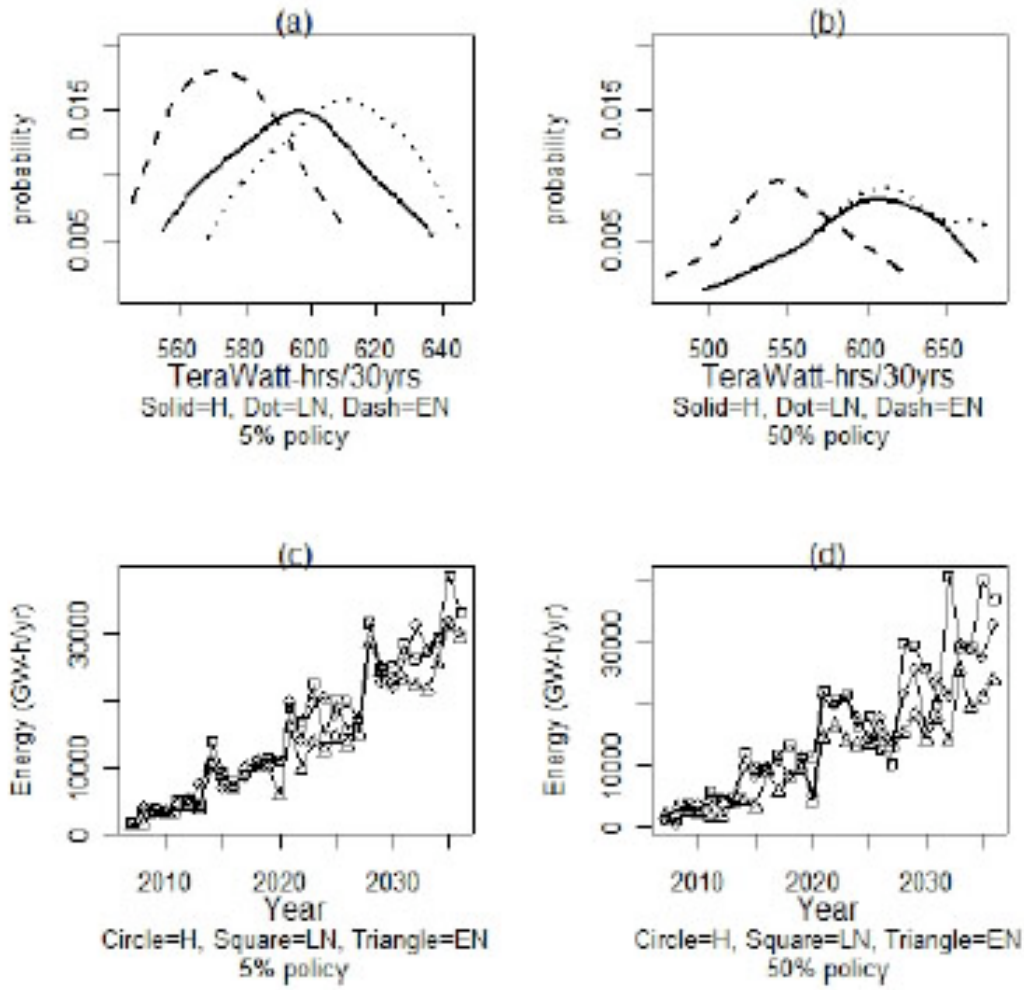
| Project Name | Reservoir Capacity ($m^3$) | Flow at Design Head ($m^3/s$) | Installed Power at Design Head (MW) |
|---|---|---|---|
| Karadobi | 32.5 billion | 948 | 1350 |
| Mabil | 13.6 billion | 1346 | 1200 |
| Mendaia | 15.9 billion | 1758 | 1620 |
| Border | 11.1 billion | 2378 | 1400 |

**Figure 3. Designations for dam heights and heads**



Economic estimates provide comparative data on which the Blue Nile hydro projects have been assessed.

**Figure 6. PDFs of total energy produced for the historic (H), La Niña (LN), and El Niño (EN) ensembles under the (a) 5 percent and (b) 50 percent flow policies during the transient period**




Note: Annual energy production under the same three ensembles for the (c) 5 percent and (d) 50 percent flow policies during the transient period.

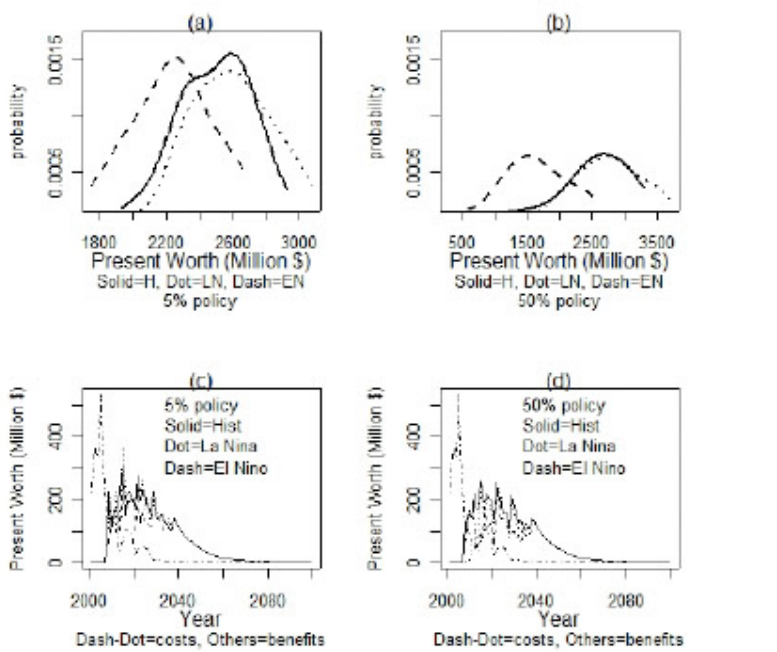
Both the (c) and (d) cases represent the identical historical ensemble member.

**Table 3. Construction and operation costs for dams**

| Project Name | Initial Construction Costs (US$ million) | Annual Costs (US$ million) |
|---|---|---|
| Karadobi | $ 2,213 | $ 15.9 |
| Mabil | $ 1,792 | $ 13.5 |
| Mendaia | $ 2,114 | $ 17.9 |
| Border | $ 1,985 | $ 17.2 |

Engineering and economic studies have shown that while hydropower can be economical, by using purely market prices, it may not be as competitive as some alternative natural resource technologies. One constraint is the low capacity factors of given projects due to erratic rainfall and storage conditions.

**Figure 5. PDFs of net present worth for the historic (H), La Niña (LN), and El Niño (EN) ensembles under the (a) 5 percent and (b) 50 percent flow policies**



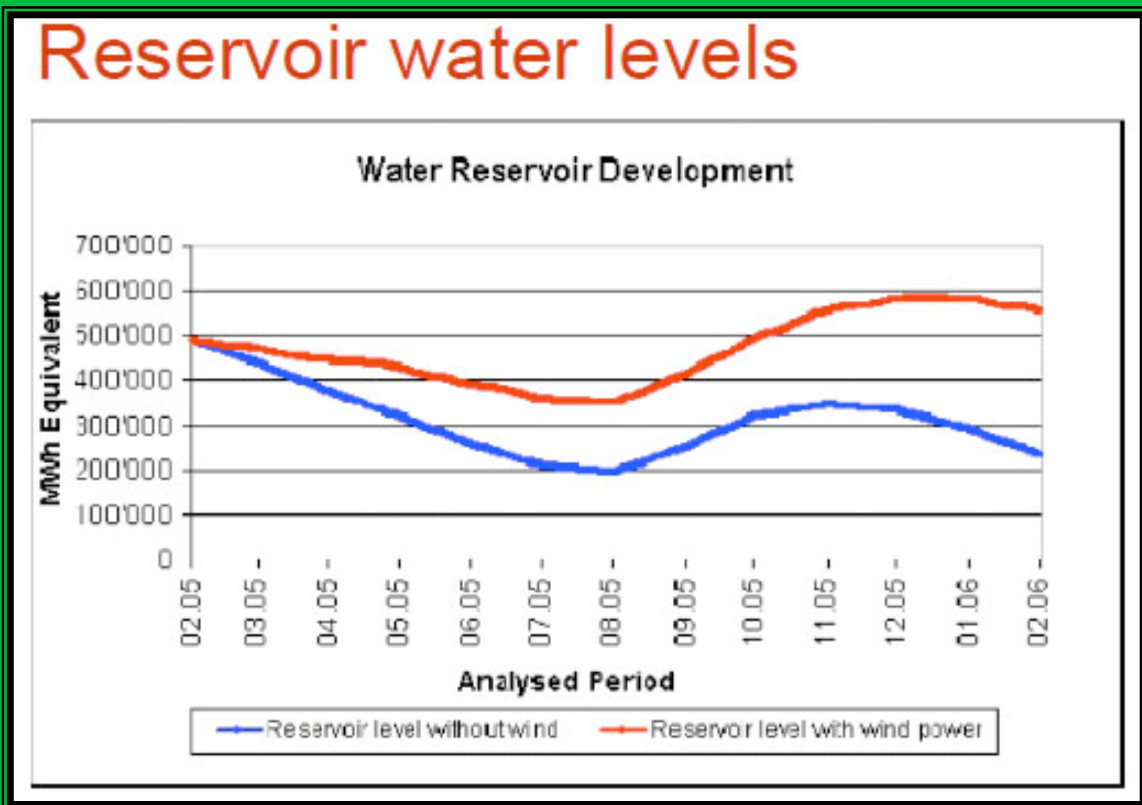

Note: Annual benefit and cost present worth curves under the same three ensembles for the (c) 5% and (d) 50% flow policies Both the (c) and (d) cases represent the identical historical ensemble member.

# Low Capacity Factors

| | Installed Capacity (MW) | Commission Year | Annual Production (MWh) | Plant Peak (MW) | Capacity Factor |
|---|---|---|---|---|---|
| Hydro | | | | | |
| Koka | 43.2 | 1960 | 58,357 | 33 | 20.2 % |
| Awash I | 32 | 1966 | 97,797 | 28 | 39.9 % |
| Awash II | 32 | 1971 | 108,924 | 32 | 38.9 % |
| Finchaa | 134 | 1973/2003 | 969,660 | 130 | 85.1 % |
| Melka Wakana | 153 | 1988 | 312,186 | 153 | 23.3 % |
| Tis Abay I | 11.4 | 1964 | 14,202 | 11 | 14.3 % |
| Tis Abay II | 73 | 2001 | 445,969 | 73 | 69.7 % |
| **Sub Total Hydro** | **478.6** | | **2,007,095** | **460.3** | **49.8 %** |
| Geothermal | | | | | |
| Aluto Langano | 7.3 | 1999 | 0 | 0 | 0.0 % |
| Diesel | | | | | |
| 10 Plants | 19.2 | 1954-1998 | 21,105 | 12 | 20.1 % |
| **Total ICS** | | | **2,028,200** | **472.3** | **49.0 %** |
| **Total SCS** | | | **35,500** | | |
| **Total EEPCO** | | | **2,063,700** | | |

(Figures for 2003)

Wind energy is one alternative to a singular expansion of hydropower capacity in Ethiopia. Low capacity factors for hydropower are but one consideration in the appeal of wind energy technology. Others are noted below. One is the savings in reservoir water levels afforded by wind energy substitution.

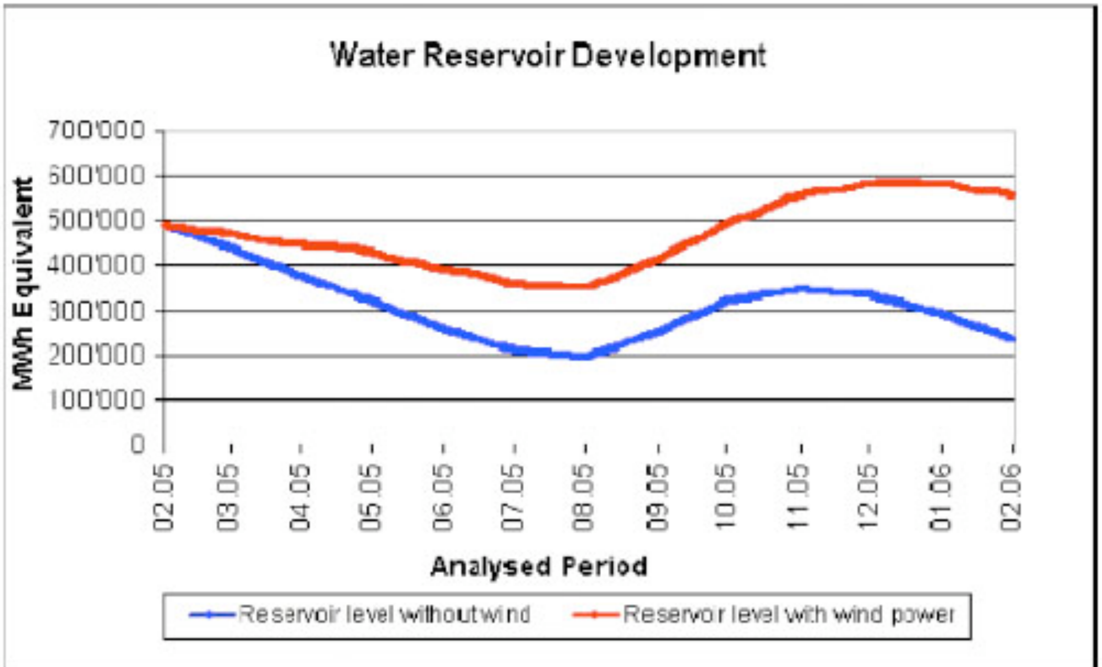



## Water Saving

| Stored energy at the end of one year at Finchaa reservoir | | | | |
| --- | --- | --- | --- | --- |
| | without wind | with Harena | with Ashegoda | with Harena and Ashe-goda |
| MWh | 281,901 | 379,307 | 513,707 | 784,326 |
| MCM[17] | 212 | 285 | 386 | 589 |

Wind energy is one alternative to a singular expansion of hydropower capacity in Ethiopia. Low capacity factors for hydropower are but one consideration in the appeal of wind energy technology. Others are noted below. One is the savings in reservoir water levels afforded by wind energy substitution.

## Reservoir water levels

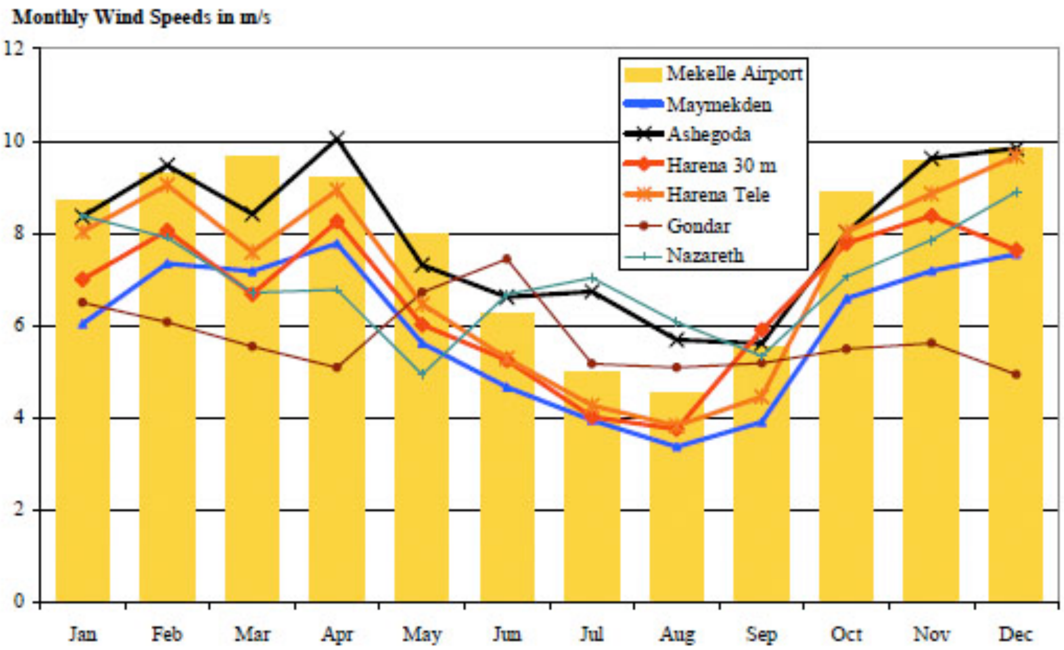



## Water Saving

| Stored energy at the end of one year at Finchaa reservoir | | | | |
|---|---|---|---|---|
| | without wind | with Harena | with Ashegoda | with Harena and Ashe-goda |
| MWh | 281,901 | 379,307 | 513,707 | 784,326 |
| MCM[17] | 212 | 285 | 386 | 589 |

Below are data on wind energy sites identified by Ethiopia Electric Power. They include estimates the prospective environmental impacts beyond the water saving already noted.

## Results of 10 Stations




## Final Site Selection

- Nazaret with the best wind resource (9.3 m/s) had a land use interest (antennae of ETV)
- selection of Ashegoda with 8.5 m/s and Harena with 6.9 m/s annual wind speeds in 40 m above ground
- EEPCO management decided for two wind parks of ~ 60 MW each
- and committed to implement immediately
- goal: first turbine on-line by June 2007 (end of dry season

Ashegoda and Harena offer some of the most promising sites.

# Feasibility Study Ashegoda

| Scenario | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|
| Type of Turbine | ENERCON E 48 | VESTAS V 52 | GAMESA G58 | ENERCON E 53 |
| Turbine Capacity [kW] | 800 | 850 | 850 | 800 |
| Number of WTG [-] | 86 | 86 | 86 | 86 |
| Installed park capacity [kW] | 68,800 | 73,100 | 73,100 | 68,800 |
| Hub Height [m] | 57 | 60 | 60 | 57 |
| Rotor Diameter [m] | 48 | 52 | 58 | 53 |
| Specific Rotor Area [$m^2$/kW] | 2.26 | 2.50 | 3.11 | 2.76 |
| Gross energy production P-75 [MWh/y] | 227,155 | 226,816 | 274,505 | 261,271 |
| Wind park array losses [%] | 5.8 | 5.0 | 5.3 | 5.7 |
| Turbine availability [%] | 95.0 | 95.0 | 95.0 | 95.0 |
| Electrical losses [%] | 2.0 | 2.0 | 2.0 | 2.0 |
| Miscellaneous losses [%] | 0.1 | 0.1 | 0.1 | 0.1 |
| **Net Output [MWh/y]** | **197,392** | **198,771** | **239,804** | **227,278** |
| **Specific Energy Production [kWh/y/$m^2$]** | **1,268** | **1,088** | **1,055** | **1,198** |
| Full load hours [h/a] | 2,869 | 2,719 | 3,280 | 3,303 |
| Capacity Factor [%] | 32.8 | 31.0 | 37.4 | 37.7 |

# Feasibility Study Harena

| Scenario | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|
| Type of Turbine | ENERCON E 48 | VESTAS V 52 | GAMESA G58 | ENERCON E 53 |
| Turbine Capacity [kW] | 800 | 850 | 850 | 800 |
| Number of WTG [-] | 61 | 60 | 57 | 61 |
| Installed park capacity [kW] | 48,800 | 51,000 | 48,450 | 48,800 |
| Hub Height [m] | 57 | 60 | 60 | 57 |
| Rotor Diameter [m] | 48 | 52 | 58 | 53 |
| Specific Rotor Area [$m^2$/kW] | 2.26 | 2.50 | 3.11 | 2.76 |
| Gross energy production P-75 [MWh/y] | 99,793 | 101,979 | 116,944 | 115,809 |
| Wind park array losses [%] | 8.4 | 8.3 | 8.9 | 9.0 |
| Turbine availability [%] | 95.0 | 95.0 | 95.0 | 95.0 |
| Electrical losses [%] | 2.0 | 2.0 | 2.0 | 2.0 |
| Miscellaneous losses [%] | 0.10 | 0.10 | 0.10 | 0.10 |
| **Net Output [MWh/y]** | **85,103** | **86,975** | **99,122** | **98,016** |
| **Specific Energy Production [kWh/y/$m^2$]** | **771** | 683 | **658** | **740** |
| Full load hours [h/a] | 1,744 | 1,705 | 2,046 | 2,042 |
| Capacity Factor [%] | 19.9 | 19.5 | 23.4 | 23.3 |

Economic analysis seems to support the choice of these sites.

## Results of Economical Analysis Ashegoda

- A 30.23 % Economic Internal Rate of Return (EIRR) for the Scenario I (EnerconE48)
- Net Present Value (ENPV) is 91.59 million USD and the
- Benefit/Cost (B/C) ratio is 1.81 calculated at 10 % discount rate.

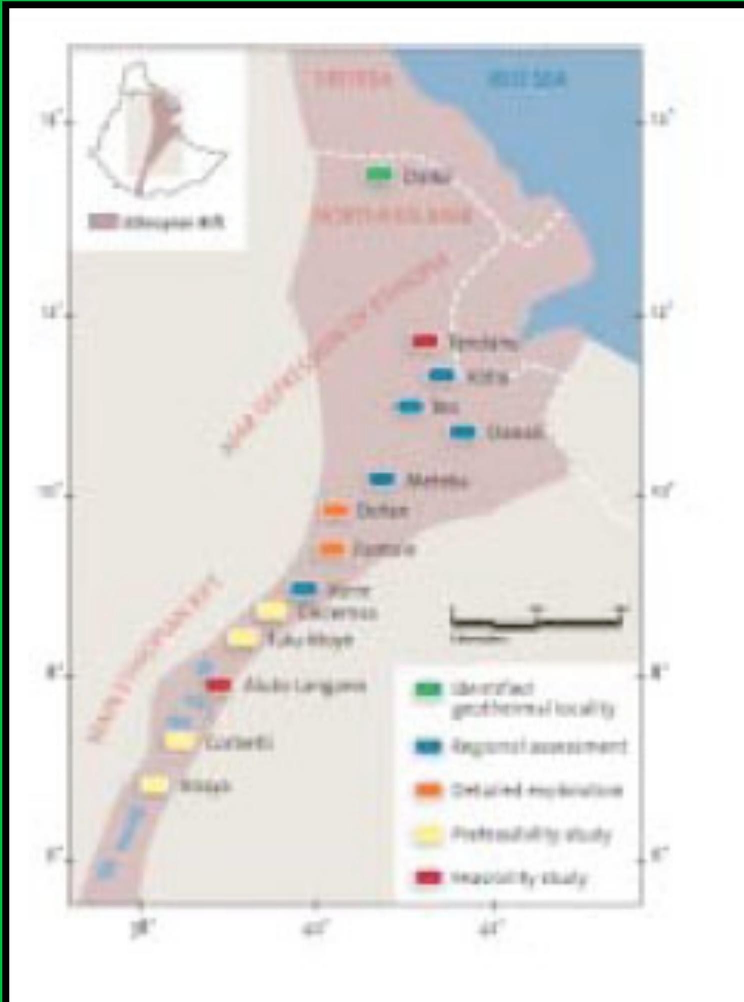
## Results of Economical Analysis Harena-Mossobo

- Scenario I (Enercon E48) produces an EIRR of 11.87 %,
- an ENPV of 6.69 millionUSD
- a Benefit/Cost (B/C) ratio of 1.09 calculated at 10 % discount rate;

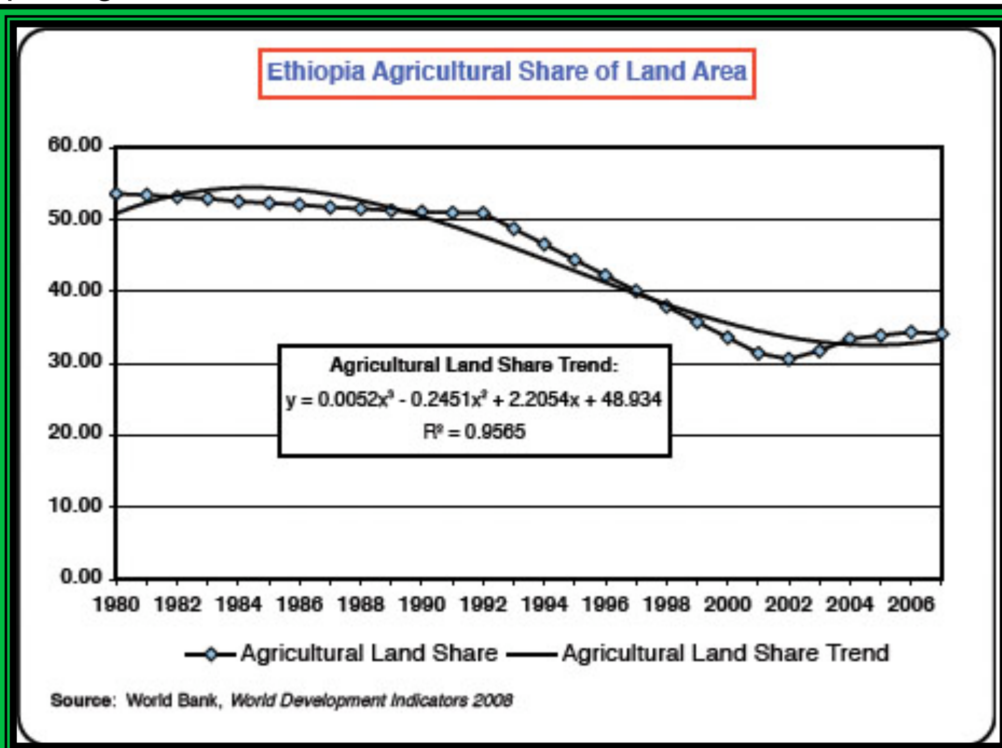
## Clean Development Mechanism (CDM) Assessment

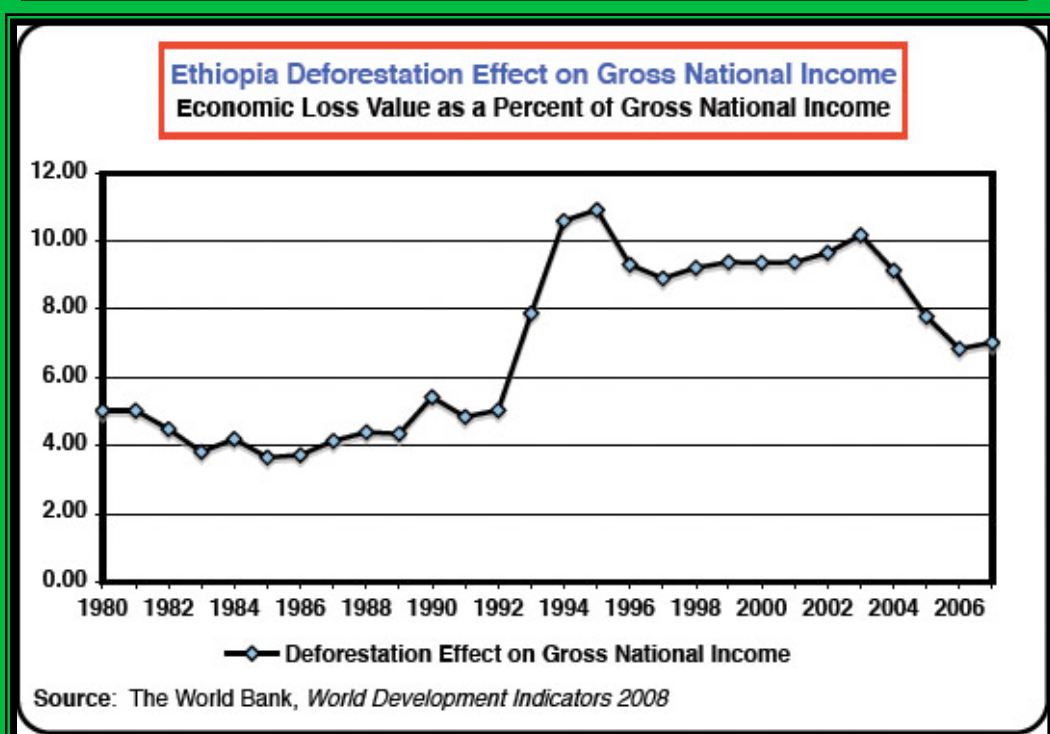
- Due to the high portion of hydropower resources in the electricity grid of Ethiopia, the emissions factor (EF) is relatively low: **16.92 tCO2/GWh.**
- for Ashegoda site considering the highest generation (239,804,000 GWh/year), it results in an annual emission reduction potential of 4,058.42 tCO2 per year the first crediting period and totalling 73,700.84 tCO2.
- For Harena –Mossobo site with the highest wind power generation (99.122GWh), it results in an annual emission reduction potential of **1,677.53 tCO2 per year for** the first crediting period and totalling **30,463.94 tCO**

Ethiopia also has geothermal electricity generating potential. Feasibility studies point to another natural resource that can be used to displace prospective use of hydropower, or more importantly, fossil fuel generating plants.

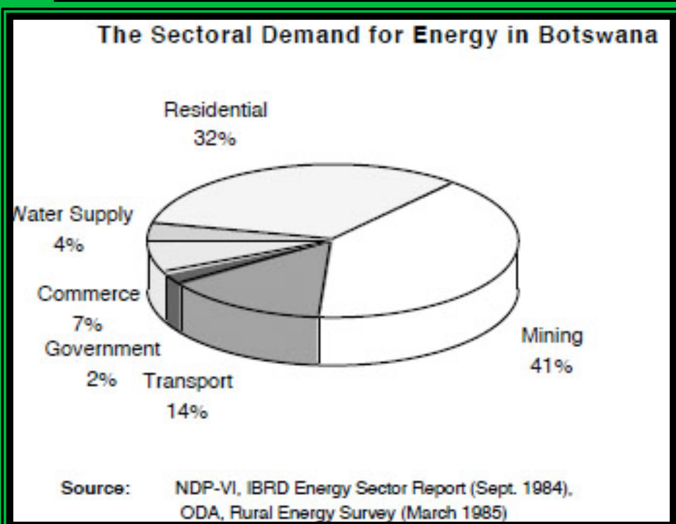


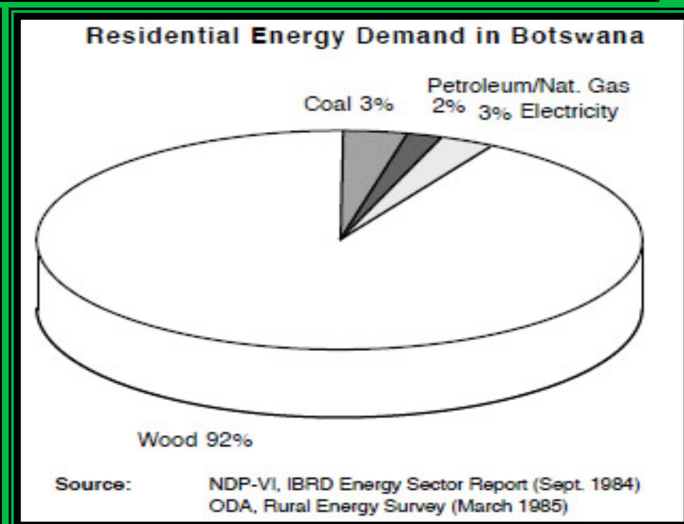
Beyond these technologies, Ethiopia faces in the short run continuing pressure on wood natural resources to meet the demand for household energy and building materials. There are two ways to address the chronic problem of deforestation. One is in terms of improving the size and yields of natural forest growth - this involves continuing research on species health and yields, as well as efforts to expand property rights to produce wood pricing valuations consistent with sustainable use.

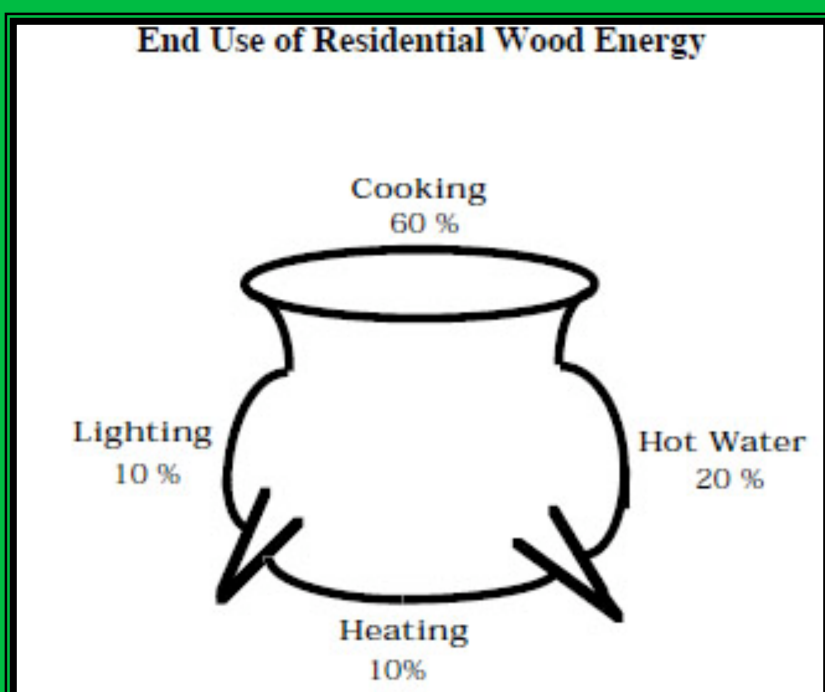


Another approach is to consider ways to conserve wood resources. This can occur through reductions in wastage rates in building materials, recycling scrap wood into plywood or particle board products, among others. In terms of wood energy use, since most consumption is for household energy use, the feasibility of wood energy stove technologies can make a significant difference. Open fire thermodynamic efficiencies are quite small, no more than on the order of 2 to 3 percent per unit of usable end use energy. Brick and metal stoves can increase these efficiencies up to 10-20 percent, representing a substantial savings in gross wood energy consumption. We demonstrate here an evaluation of such technologies based on field testing in Botswana.



Some results from the Botswana Renewable Energy Technology Study:

**Sensitivity Analysis of BRET Stoves**

| Model and Parameters: | Delivered Cost Basis (financial analysis) NPV | IRR (Pula) | B/C | Total R&D Unit Cost (economic analysis) NPV | IRR (Pula) | B/C |
|---|---|---|---|---|---|---|
| **A. Discount rate** | | | | | | |
| 1. **"B" Model**: | | | | | | |
| a. 6 percent | 37.5 | 151.9 | 1.93 | 19.8 | 34.4 | 1.34 |
| b. 10 percent | 33.4 | 151.9 | 1.86 | 15.7 | 34.4 | 1.27 |
| c. 20 percent | 25.4 | 151.9 | 1.70 | 7.7 | 34.4 | 1.14 |
| d. 30 percent | n/a | 151.9 | n/a | 2.0 | 34.4 | 1.03 |
| 2. **"Super B" Model:** | | | | | | |
| a. 6 percent | 33.9 | 112.8 | 1.77 | 16.2 | 27.8 | 1.26 |
| b. 10 percent | 29.9 | 112.8 | 1.70 | 12.2 | 27.8 | 1.20 |
| c. 20 percent | 22.2 | 112.8 | 1.56 | 4.5 | 27.8 | 1.07 |
| d. 30 percent | n/a | 112.8 | n/a | -1.1 | 27.8 | 0.98 |
| 3. **"Delta 3" Model**: | | | | | | |
| a. 6 percent | 44.1 | 336.8 | 2.31 | 26.1 | 48.5 | 1.50 |
| b.10 percent | 39.8 | 336.8 | 2.23 | 21.8 | 48.5 | 1.43 |
| c.20 percent | 31.4 | 336.8 | 2.04 | 13.4 | 48.5 | 1.27 |
| d.30 percent | n/a | 336.8 | n/a | 7.4 | 48.5 | 1.15 |
| 4. **"Delta 6" Model**: | | | | | | |
| a. 6 percent | 44.3 | 338.3 | 2.33 | 26.6 | 49.8 | 1.52 |
| b.10 percent | 40.0 | 338.3 | 2.24 | 22.3 | 49.8 | 1.44 |
| c.20 percent | 31.5 | 338.3 | 2.05 | 13.9 | 49.8 | 1.29 |
| d.30 percent | n/a | 338.3 | n/a | 7.8 | 49.8 | 1.17 |

B. **Common technical and economic parameters used for all four models and for the range of discount rates listed**:

1. **Technical**:
   - a. Fuelwood Savings
   - b. 527 Kg per year (20 percent)
   - c. Stove durability:
     - i. 5 year life
     - ii. Replace grate in years 2 and 4
     - iii. Replace liner in year 3

Another application is in terms of alternative water supply technologies for agriculture. We illustrate here some comparisons based on diesel, solar, and wind technologies for the Sudan. In this study, domestic fuel subsidies created a bias in favor of diesel over wind and solar alternatives.

The subsidy derived in part from a parallel foreign exchange market as well as from an explicit controlled price subsidy directly to agricultural users of diesel fuel. Part of this bias stems from the relatively low capital cost of diesel engines in comparison to the higher capital costs of wind and solar technologies.

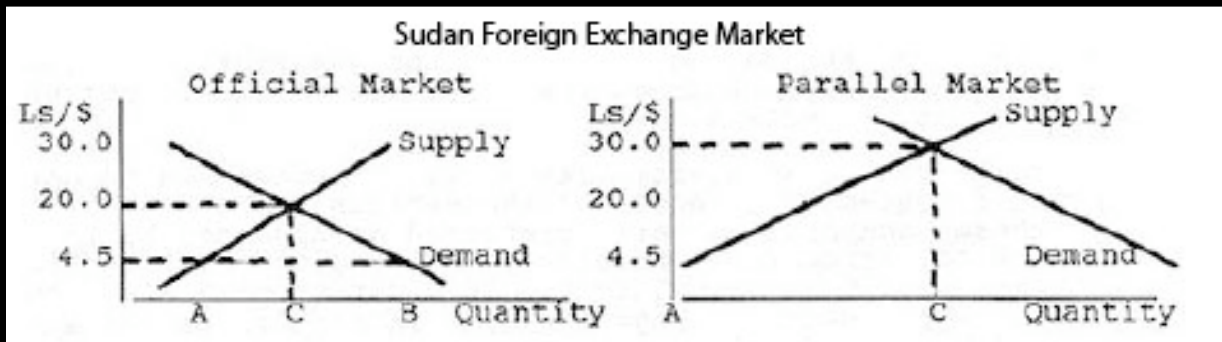



**Table 1**
**Sensitivity Tests for Discount Rates**
**Present Value per Cubic Meter, in Ls**

| | Financial Analysis | | | |
|---|---|---|---|---|
| Rates | **Diesel** | **Solar** | **Wind** | Assumptions used in Discount Rate Tests: |
| 12% | 20.65 | 18.22 | 17.36 | 1.0 Shadow price ofunskilled labor |
| 15% | 23.56 | 21.46 | 20.51 | 1.0 Shadow foreign exchange rate |
| 20% | 28.69 | 27.17 | 26.07 | 0% taxes on equipment |
| 25% | 34.04 | 33.13 | 31.86 | 12 = foreign exchange rate |
| 30% | 39.53 | 39.23 | 37.79 | 11.5 = Ls Fuel Cost/Imperial gallon |
| 35% | 45.08 | 45.43 | 43.79 | $5.25 per peak watt solar energy value |
| 40% | 50.67 | 51.68 | 49.83 | 100 Depth of well, in meters |
| 45% | 56.29 | 57.96 | 55.90 | 2500 well cost per meter, in Ls |
| 50% | 61.93 | 64.26 | 61.97 | Base Case Technical Assumption of no loans |

| | Economic analysis | | | |
|---|---|---|---|---|
| Rates | **Diesel** | **Solar** | **Wind** | Assumptions used in Discount Rate Tests: |
| 12% | 22.43 | 14.41 | 19.28 | .5 Shadow price ofunskilled labor |
| 15% | 25.41 | 16.84 | 22.79 | 1.5 Shadow foreign exchange rate |
| 20% | 30.67 | 21.12 | 28.98 | 0% taxes on equipment |
| 25% | 36.16 | 25.61 | 35.43 | 12 = foreign exchange rate |
| 30% | 41.78 | 30.21 | 42.03 | 11.5 = Ls Fuel Cost/Imperial gallon |
| 35% | 47.48 | 34.88 | 48.72 | $5.25 per peak wtt solar |
| 40% | 53.22 | 39.60 | 55.45 | 100 Depth of well, in meters |
| 45% | 58.99 | 44.35 | 62.21 | 2500 well cost per meter, in Ls |
| 50% | 64.78 | 49.12 | 68.98 | Base Case Technical Assumption of no loans |

For the Sudan,at least, even though it has made significant discoveries of crude oil, the efficiency with which this is used depends in part on the distortions introduced by foreign exchange rate decisions and on explicit subsidies to the agricultural sector.

## Sensitivity Test Financial Regression Analysis

Given the parametric variations used in the sensitivity tests, one can derive the relative importance of a variable to the level of the present value per cubic meter of water. Since all variables are perfectly correlated by definition, the purpose of this comparison is only to assess the relative contribution of a variable and the direction of causation on water life cycle unit costs. Listed below are the results of linear and multipler linear OLS regressions of the sensitivity variables, with standard errors listed in parentheses.

| Dependent Variable | Independent Variables | | | | | | |
|---|---|---|---|---|---|---|---|
| 1. Diesel | =7.0800 | +1.09<br>(0.01) | Disc.Rate | | | | |
| 2. Diesel | =6.5000 | +0.09<br>(0.01) | Forex | +1.07<br>(0.01) | Disc.Rate | | |
| 3. Diesel | =22.1500 | +0.0630<br>(0.01) | Forex | +0.07<br>(0.001) | Fuel Cost | | |
| 4. Diesel | =7.3300 | +0.995<br>(0.00430) | Disc.Rate | +0.057<br>(0.00140) | Forex | +0.057<br>0.00043* | Fuel |
| 5. Solar | = -0.5820 | +1.091<br>(0.01858) | Disc.Rate | +0.470<br>(0.00579) | Foreg | -0.00075<br>(0.00183) | Fuel |
| 6. Wind | =0.6039 | +1.076<br>(0.01389) | Disc.Rate | +0.3129<br>(0.00447) | Forex | -0.00053<br>0.00137* | Fuel |
| 7. Diesel | =2.3500 | +1.18<br>(0.030) | Disc.Rate | +0.11<br>(0.010) | Forex | -0.22000<br>(0.000) | Loans |
| 8. Solar | = -13.7500 | +1.42<br>(0.05) | Disc.Rate | +0.82<br>(0.03) | Forex | +0.267<br>(0.01) | Loans |
| 9. Wind | = -9.9200 | +1.35<br>(0.04) | Disc.Rate | +0.57<br>(0.05) | Forex | +0.250<br>(0.02) | Loans |
| 10. Diesel | =0.6100 | +1.08<br>(0.01) | Disc.Rate | +0.09<br>(0.00) | Forex | +0.03<br>(0.00) | Tax Rate |
| 11. Solar | = -8.3900 | +1.36<br>(0.04) | Disc.Rate | +0.69<br>(0.02) | Forex | +0.09<br>(0.01) | Tax Rate |
| 12. Wind | = -5.0000 | +1.27<br>(0.03) | Disc.Rate | +0.47<br>(0.01) | .Forex | +0.06<br>(0.01) | Tax Rate |

* Denotes variable is not significant at the 5 percent level.

As we have seen, creating conditions for sustainable use of natural resources depends in part on the role of property rights in establishing prices at competitive levels consistent with prevailing opportunity costs. We illustrate here a way of assessing the economic importance of institutions, notably the significance of aggregate country risk in general, and through its determinants, the importance of property rights and judicial independence in achieving sustainable rates of growth. While not specifically directed at natural resource use, because traditional natural resource use is affected by conditions of market failure arising from common property regimes, how a country chooses to define, uphold, and allocate property rights may have a critical bearing on sustainable natural resource use. The following sections derive from a paper published in 2008 (LeBel)

**Table 1**
**Sub-Saharan Africa Basic Growth Regressions**

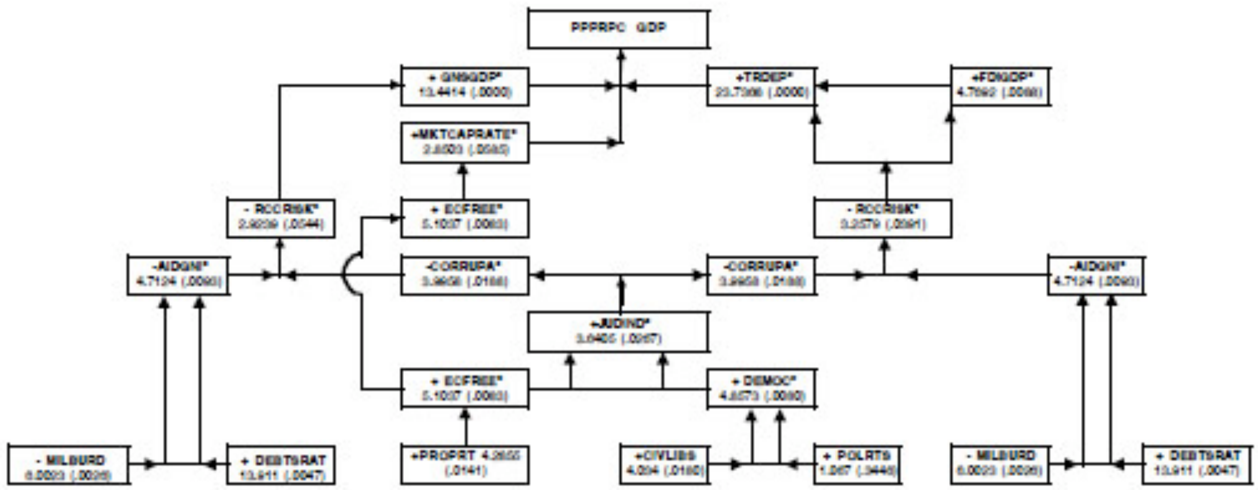
*Dependent Variable: PPP Real GDP Per Capita*

| | | | | | | |
|---|---|---|---|---|---|---|
| Constant | 1608.842 | 1897.491 | 1612.915 | 1604.893 | 1607.098 | 1861.125 |
| GNSGDP | 7.656 | 4.951 | 7.363 | 7.310 | 6.863 | 5.244 |
| | (10.758) | (6.269) | (10.430) | (10.050) | (9.328) | (6.739) |
| TRDEP | 2.443 | 1.988 | 2.226 | 2.499 | 2.404 | 1.911 |
| | (8.572) | (5.614) | (7.728) | (8.552) | (7.870) | (5.230) |
| MKTCAPRATE | | | 1.080 | | 0.736 | 0.855 |
| | | | (1.761) | | (1.182) | (1.3480) |
| FDIGDP | | | | 3.448 | 3.773 | 2.441 |
| | | | | (2.697) | (2.750) | (1.455) |
| RCCRISK | | -4.923 | | | | -4.407 |
| | | (6.893) | | | | (6.033) |
| Number of Observations | 750 | 750 | 750 | 750 | 750 | 750 |
| Adj. R-Sq. | 0.9650 | 0.9702 | 0.9622 | 0.9643 | 0.9584 | 0.9702 |
| F | 667.85 | 764.32 | 597.21 | 632.62 | 524.41 | 718.01 |

*Notes:*
1. Panel regression estimates are based fixed effects using cross-section weights.
2. T-statistics are reported in parentheses.

An institutional model illustrates the various determinants and their relative contributions to aggregate country risk.

## Figure 1
## Risk Model Structure




## Table 2
## Determinants of Aggregate Country Risk

*Dependent Variable: RCCRISK (Revised Country Composite Risk Index)*

| | | | | | |
|---|---|---|---|---|---|
| Constant | 43.873 | 33.116 | 40.470 | 44.597 | 50.609 |
| AIDGNI | 0.188 | 0.173 | 0.196 | 0.165 | 0.170 |
| | (6.195) | (5.781) | (7.513) | (6.612) | (6.431) |
| CORRUPA | | 1.527 | 1.033 | 1.185 | 0.867 |
| | | (5.345) | (4.028) | (4.639) | (3.040) |
| DEMOC | | | -0.407 | -0.348 | -0.301 |
| | | | (19.666) | (15.477) | (12.417) |
| ECFREE | | | | -3.687 | -3.064 |
| | | | | (5.532) | (4.188) |
| JUDIND | | | | | -1.143 |
| | | | | | (4.710) |
| Number of Observations | 750 | 750 | 750 | 750 | 750 |
| Adj. R-Sq. | 0.8691 | 0.8386 | 0.8916 | 0.8868 | 0.8389 |
| F | 4973.18 | 1947.34 | 2053.90 | 1468.00 | 781.15 |

*Notes:*

1. Panel regression estimates are based on cross-section weights, no effects specified.
2. T-statistics are reported in parentheses.

A nested regression model illustrates the sequential impact of various institutional determinants on risk and the level of PPP real per capita GDP. From this we can calibrate the present value of one unit changes on institutional variables in affecting the level of risk and thus the level of per capita income.

## Table 3
## Nested Regression Estimates

| Dependent Variable: | DEMOC[3] | ECFREE[3] | JUDIND[4] | CORRUPA[4] | AIDGNI[5] | RCCRISK[6] | GNSGDP[7] | TRDEP[8] | MKTCAPRATE[9] | FDIGDP[8] | PPPRPCGDP[4] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CONSTANT | -8.173 | 1.246 | 3.769 | 7.916 | 11.462 | 31.701 | 677.806 | 133.203 | 11.262 | 171.300 | -1662.856 |
| CIVLIBS | 2.730 | | | | | | | | | | |
| | (42.534) | | | | | | | | | | |
| POLRTS | 3.737 | | | | | | | | | | |
| | (67.292) | | | | | | | | | | |
| PROPRT | | 0.106 | | | | | | | | | |
| | | (7.142) | | | | | | | | | |
| DEMOC* | | | 0.026 | | | | | | | | |
| | | | (10.675) | | | | | | | | |
| ECFREE* | | | 0.979 | | | | | | 0.448 | | |
| | | | (15.225) | | | | | | (3.460) | | |
| JUDIND* | | | | -0.198 | | | | | | | |
| | | | | (3.106) | | | | | | | |
| MILBURD | | | | | -1.124 | | | | | | |
| | | | | | (6.134) | | | | | | |
| DEBTSRAT | | | | | 0.114 | | | | | | |
| | | | | | (6.137) | | | | | | |
| AIDGNI* | | | | | | 0.314 | | | | | |
| | | | | | | (8.041) | | | | | |
| CORRUPA* | | | | | | 2.909 | | | | | |
| | | | | | | (8.465) | | | | | |
| RCCRISK* | | | | | | | -12.294 | -1.670 | | -3.676 | |
| | | | | | | | (3.225) | (2.816) | | (5.474) | |
| GNSGDP* | | | | | | | | | | | 141.747 |
| | | | | | | | | | | | (15.120) |
| TRDEP* | | | | | | | | | | | 16.021 |
| | | | | | | | | | | | (14.388) |
| MKTCAPRATE* | | | | | | | | | | | 62.746 |
| | | | | | | | | | | | (53.057) |
| FDIGDP* | | | | | | | | 3.209 | | | |
| | | | | | | | | (6.842) | | | |
| Number of Observations | 750 | 750 | 750 | 750 | 750 | 750 | 750 | 750 | 750 | 750 | 750 |
| Adj. R-Sq. | 0.9830 | 0.9701 | 0.9336 | 0.9789 | 0.7229 | 0.8402 | 0.4769 | 0.8020 | 0.8932 | 0.8130 | 0.8998 |
| F | 1395.31 | 810.92 | 5267.19 | 34796.17 | 64.04 | 196.24 | | 98.89 | 357.25 | | 2240.20 |

Notes:
1. T-statistics are reported in parentheses
2. Starred variables are based on predicted values from a nested regression.
3. Estimate based on fixed effects using cross-section weights
4. Estimate based on no effects with cross-section weights.
5. Estimate based on two-stage least squares with cross-section weights and fixed effects.
6. Estimate based on fixed cross-section specification with period GLS weights.
7. Estimate based on two-stage least squares with rccrisk instrument, fixed cross-section specification with cross-section GLS weights.
8. Estimate based on two-stage least squares, with fixed effects and cross-section weights, d(RCCRISK) as instrument.
9. Estimate based on two-stage least squares with ecfree(-1) as instrument, fixed cross-section and cross-section GLS weights.

## Table 4
## Effects of One-Unit Changes in Policy Variables on PPPRPCGDP (n=30)

| Policy Variable Change | PPP RPCGDP | Annual Difference | Percent Change | Present Value at: | Present Value at: |
|---|---|---|---|---|---|
| Base Case | $1,617.17 | | | 4.65% | 8.55% |
| AIGDNI+1 | $1,005.19 | -$611.98 | -37.84% | -$13,164.67 | -$7,161.05 |
| DEBTSRAT+1 | $1,547.47 | -$69.70 | -4.31% | -$1,499.42 | -$815.62 |
| TRDEP+1 | $1,633.19 | $16.02 | 0.99% | $344.54 | $187.42 |
| DEMOC+1 | $1,636.54 | $19.37 | 1.20% | $416.61 | $226.62 |
| FDIGDP+1 | $1,668.59 | $51.42 | 3.18% | $1,106.05 | $601.65 |
| MKTCAPRATE+1 | $1,669.92 | $52.75 | 3.26% | $1,134.66 | $617.21 |
| CIVLIBS+1 | $1,670.05 | $52.88 | 3.27% | $1,137.46 | $618.73 |
| DEBTSRAT-1 | $1,686.88 | $69.71 | 4.31% | $1,499.49 | $815.66 |
| POLRTS+1 | $1,689.56 | $72.39 | 4.48% | $1,557.15 | $847.02 |
| PROPRT+1 | $1,700.55 | $83.38 | 5.16% | $1,793.56 | $975.62 |
| GNSGDP+1 | $1,758.92 | $141.75 | 8.77% | $3,049.18 | $1,658.63 |
| JUDIND+1 | $2,399.64 | $782.47 | 48.38% | $16,832.02 | $9,155.94 |
| ECFREE+1 | $2,406.96 | $789.79 | 48.84% | $16,989.48 | $9,241.59 |
| RCCRISK-1 | $3,567.05 | $1,949.88 | 120.57% | $41,944.74 | $22,816.25 |
| CORRUPA-1 | $7,278.24 | $5,661.07 | 350.06% | $121,777.94 | $66,242.30 |

Present Value effects are computed using, respectively, mean and median levels of sample real interest rates.