MCA4climate

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MCA4climate: A practical framework for planning pro-development climate policies

Mitigation Theme Report: Increasing the Share of Low-Carbon Energy Sources in the Fuel Mix

Contribution to the MCA4climate initiative

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Practical Note

For an overview of the MCA4climate initiative and a step-by-step guidance on how the theme-specific information reported below may be practically applied in countries wishing to develop pro-development climate policy planning, please see the main MCA4climate report and other associated documents available for download at www.mca4climate.info. Also, specifically related to the mitigation theme of increasing the share of low-carbon energy sources in the fuel mix, a case study on the electricity sector in South Africa was carried out (also available on the MCA4climate website). For further information, please contact the UNEP team, Serban Scrieciu, Sophy Bristow, Daniel Puig or Mark Radka at unep.tie@unep.org.

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1. Introduction

There are multiple means for addressing climate change that are addressed in this report. International negotiations have focused primarily on mitigation of emissions of carbon dioxide and other heat trapping greenhouse gases (GHGs) with an intense effort to "carbonize" emissions and solutions. The Kyoto Protocol is essentially an *environmental protection*, pollution control treaty that addresses emissions of heat trapping greenhouse gases yet ignores the underlying economic development and social factors that cause those emissions. There is an implicit belief on the part of most political leaders that growing GHG emissions are essential to economic development, and that curtailing those emissions will impede development. Furthermore, cutting emissions is referred to as "burden sharing," so it is not surprising that no one wishes to "share the pain." Basing the treaty on sustainable development in which all parties are assured access to clean energy services that do not damage the climate system would allow all to "share the gain" instead (Mooomaw and Papa, 2011). The relative annual emission of carbon dioxide from the three fossil fuels is shown in Figure 1.

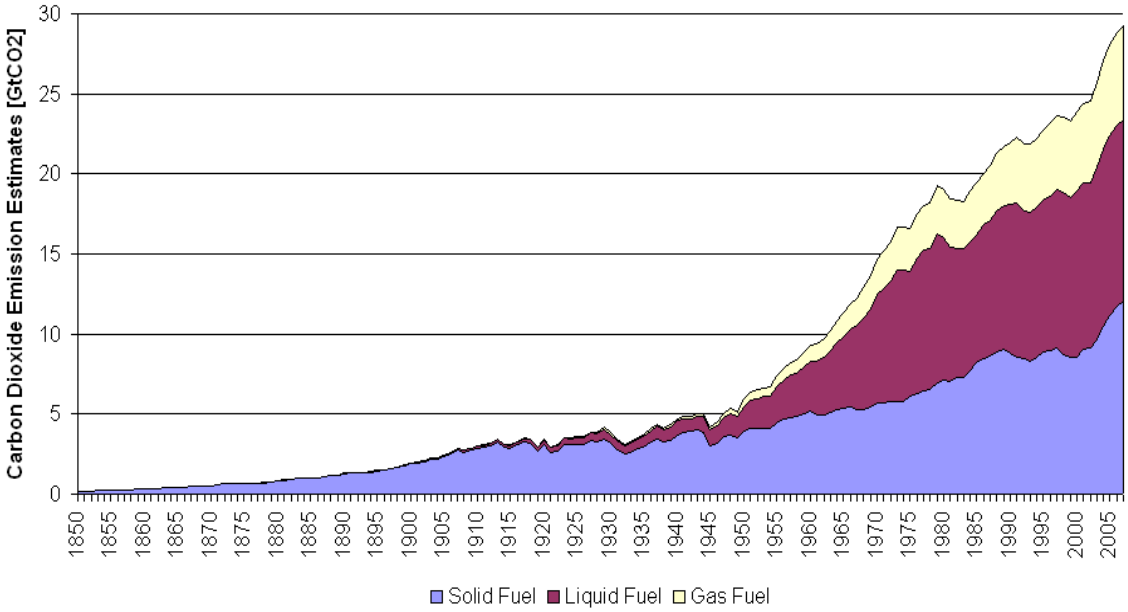

Figure 1. Annual emissions of carbon dioxide from the combustion of fossil fuels. (Boden and Marland, 2010)

While there has been considerable attention to the *economic costs* of both climate change and the costs of reducing emissions to avoid climate change (Stern, 2006; Ackerman, 2010) there has been little consideration of the *social consequences* of alternative means of reducing those emissions. This approach has lead to major disagreements between developed and developing countries over the appropriate course of action. In this section of the report, we will examine the *social implications* of alternative, low-carbon energy sources used to provide energy services using

multi-criteria analyses. We will also examine how these alternatives might also address adaptation to climate change, which is becoming an increasing focus of concern as climate change continues to accelerate.

2. The role of low-carbon energy sources in the fuel mix.

Globally, nearly 60% of heat of global warming is caused by carbon dioxide from the combustion of fossil fuels (UNDESA, 2009). Methane leaks from natural gas and oil production and use and other GHGs associated with primary energy contribute more to global warming and black carbon from biomass fuels and diesel emissions contribute to global warming as well (Molina et al, 2009; Montgomery et al, 2009). Yet, fossil fuels constitute over 80% of the primary energy that is used. (IPCC, 2011) If climate change is to be addressed effectively, it will be necessary to replace significant portions of primary fuels with low-carbon alternatives. This technical finding is the easy part. The challenge is finding a means of doing so in ways that support development and meet social concerns such as equity, community interests in a manner that is economically cost-effective while addressing environmental and climate concerns.

The technical dimension of the problem is relatively straightforward. People do not need energy; they need energy services such as:

- Cooking
- Lighting
- Refrigeration
- Communications and entertainment
- Mechanical work
- Transportation
- Heating for comfort and hot water
- Agriculture, Manufacturing and Processing

End use energy to supply these services is provided by different energy carriers such as heat, electricity or mechanical work. The end use carriers of energy come from through a technological conversion process that utilizes a source of primary energy such as biomass or fossil fuels, nuclear energy, solar, wind, hydro, geothermal or ocean energy. At each stage of transformation there is energy that leaves the system and does not get to the end user. The flow of energy from source to end-use as energy services is shown in Figure 2.

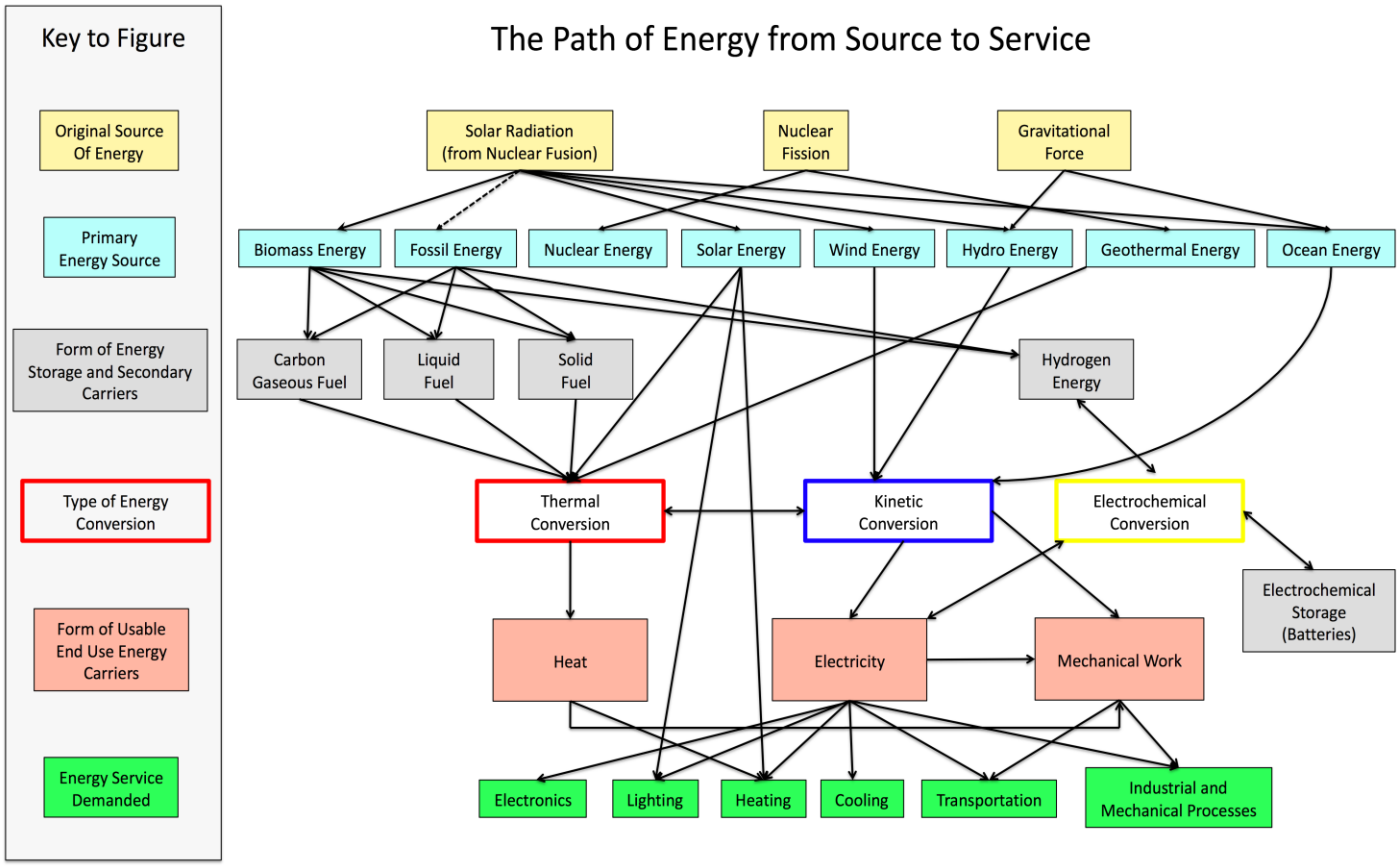

Figure 2. The path of energy flow from source to service. (Strong)

There are three major aspects of energy sources that relate to how they might affect climate.

- How much heat trapping greenhouse gases are released during extraction, production or use.
- Renewability of the resource defined as the rate of regeneration from natural energy flows exceeds the rate of use. Fossil fuels do not meet this definition. Biomass may meet this definition if plant or animal material grows at a rate that equals or exceeds the rate at which it is combusted. Geothermal fields are renewable if the rate at which heat flows into them equals or exceeds the rate that it is drawn out for use. Hydropower is renewable if the rate at which it is utilized to make electricity or mechanical energy does not exceed the flow rate. Extracting energy from wind or ocean currents could "deplete" the resource in extreme cases, but this is not likely to happen in practice. Utilization of solar energy does not affect the rate at which it arrives at the surface of the earth.

- Sustainability refers to the endurance of the resource over very long time periods. Sustainability also refers to meeting the economic, social and environmental needs of future generations. This is all about providing appropriate services for people at each stage of development.

How much carbon dioxide or other heat trapping greenhouse gases are released when utilizing a source of energy? Each of the combustible sources, coal, oil and natural gas emit carbon dioxide when they are burned, as does biomass. Fossil fuels may also release the second most important greenhouse gas, methane, during production, transportation or use. The relative amount of carbon dioxide that is emitted by each during combustion is provided in Table 1. Non-combustible sources, solar, wind, hydro, geothermal and ocean energy and nuclear power release relatively little of these gases (1-10%). The relative amount of carbon dioxide that is released when generating the carrier electricity from different sources is shown in Figure 3 (Weisser, 2007; Sovacool, 2008; Jacobson, 2009).

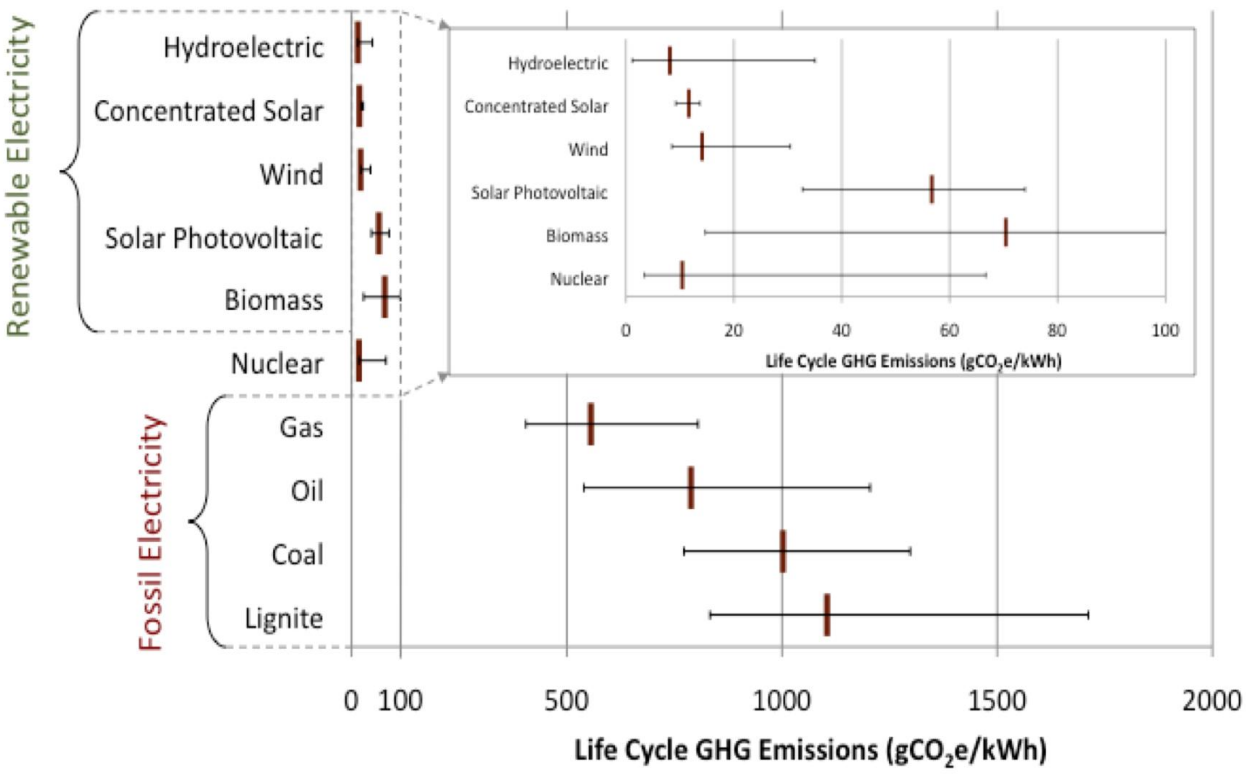

Figure 3. Lifecycle carbon dioxide emissions from fossil fuels, nuclear power, biomass and renewable energy produced electric power. See text for discussion of biomass. (Stratton)

Energy use is not simply about carbon dioxide emissions and climate change. Many energy transformations require major water use, appropriate large amounts of land and produce major quantities of air and/or water pollution. Non-combustible renewable energy sources have the lowest overall use of water (other than hydro),

and produce relatively few pollutants. They have the further advantage of not requiring a constant supply of fuels since the energy comes from natural flows. A summary of the multiple environmental impacts of a range of energy supply sources and fuels is provided in Figure 4.

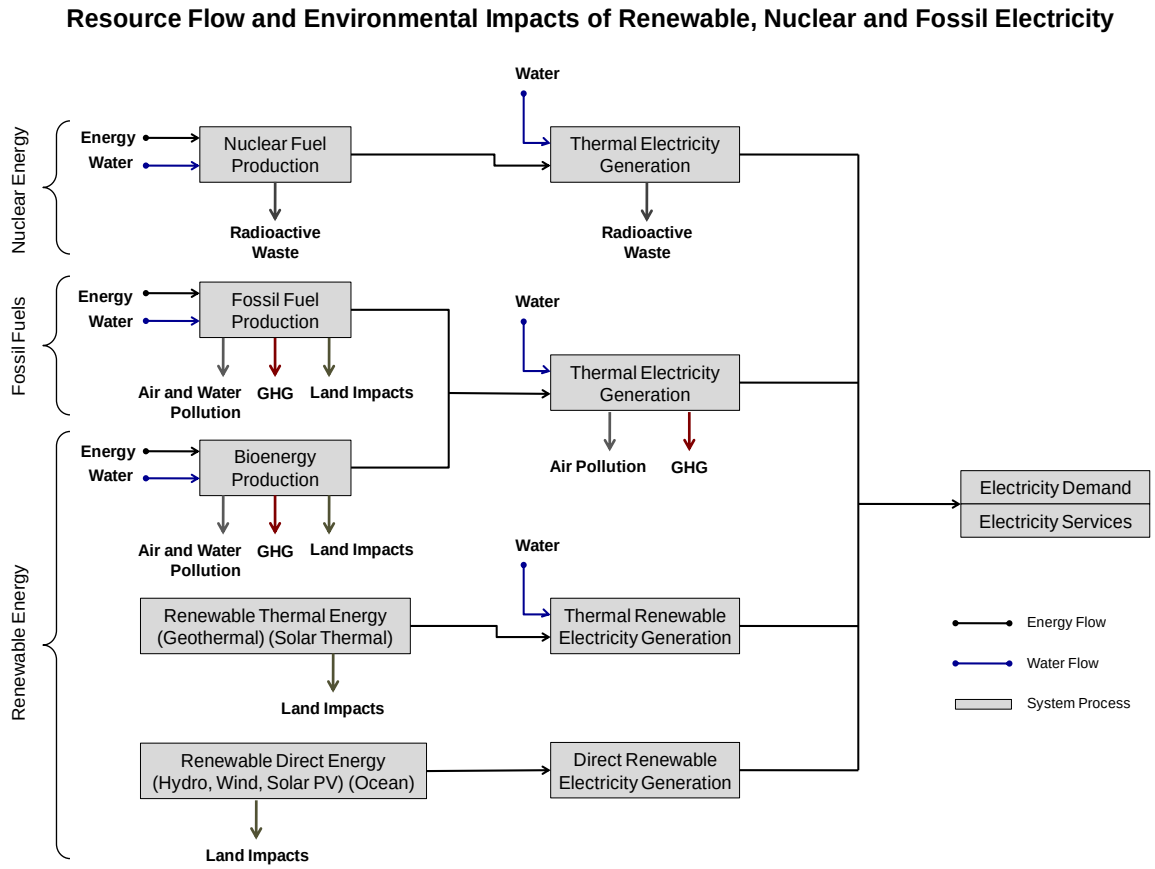

Figure 4. Comparison of resource flow and environmental impacts including greenhouse gases of renewable energy, nuclear power and fossil fuel produced electricity. (Spang and Stratton)

3. Relating the need for energy services to stages of development

Energy service needs vary with levels of development and degrees of urbanization (Bazilian, 2010). In this analysis, potential energy service needs identified in Part 2 will be paired with each of four different stages of development. Several of the primary energy

- Rural and urban, poorest, least developed countries (Kenya, Bangladesh, Honduras)
- Urban developing countries (India, Thailand, Ecuador)
- Emerging economies (Brazil, China, Korea, Mexico, South Africa)
- Developed countries (United States, Europe, Japan)

This section will establish sample relationships among energy services, stage of development and primary energy source. The climate implications of each primary source will be summarized in section 4, and the social implications will be discussed in Section 5.

	Least Developed Countries	Developing Countries	Emerging Economies	Developed Countries
Cooking	Solid biomass Biogas Solar	Fossil fuel gas Biogas	Fossil fuel gases Biogas Electricity	Fossil fuel gases Biogas Electricity
Lighting	Kerosene Candles Flashlights Solar	Kerosene Fossil electric Solar electric Hydroelectric Wind electric Geo electric	Fossil electric Solar electric Hydroelectric Wind electric Geo electric Nuclear electric	Fossil electric Solar electric Hydroelectric Wind electric Geo electric Nuclear electric
Refrigeration	None	Fossil electric Solar electric Hydroelectric Wind electric Geo electric	Fossil electric Solar electric Hydroelectric Wind electric Geo electric Nuclear electric	Fossil electric Solar electric Hydroelectric Wind electric Geo electric Nuclear electric
Communications and entertainment	Solar electric Fossil electric	Fossil electric Solar electric Hydroelectric Wind electric Geo electric	Fossil electric Solar electric Hydroelectric Wind electric Geo electric Nuclear electric	Fossil electric Solar electric Hydroelectric Wind electric Geo electric Nuclear electric
Mechanical work	Animal Human	Animal Wind work Hydro work Fossil fuel work/electric Hydro electric Solar electric	Fossil electric Solar electric Hydroelectric Wind electric Geo electric Nuclear electric	Fossil electric Solar electric Hydroelectric Wind electric Geo electric Nuclear electric
Transportation	Animal Bicycle Fossil vehicle	Fossil vehicle Biofuel vehicle Bicycle Public transportation	Fossil vehicle Biofuel vehicle Bicycle Public transportation	Fossil vehicle Biofuel vehicle Bicycle Public transportation
Heating for comfort and hot water	Biomass Biogas	Biomass Biogas Fossil fuel gas Solar thermal	Biogas Fossil fuel gas Solar thermal	Biogas Fossil fuel gas Solar thermal

Agriculture, Manufacturing and Processing	Animal	Animal Wind work Hydro work Fossil fuel work/electric Hydro electric Solar electric	Fossil electric Solar electric Hydroelectric Wind electric Geo electric Nuclear electric	Fossil electric Solar electric Hydroelectric Wind electric Geo electric Nuclear electric

Table 1. Energy services, stage of development and potential primary energy source

4. Examples of energy services, and the climate and social implications of alternative means of supplying them

Figure 1 suggests that there are three major means of delivering energy to the end user: as heat, electricity or mechanical work. Each of these energy forms can be produced in a variety of ways from renewable sources, biomass, fossil fuels, or nuclear power. Energy services will be grouped under each of the three end use forms of energy. In this section, a selection of energy services will be paired with primary energy sources, and the production of the energy to supply those services will be discussed in terms of its climate and social implications.

Cooking and Heating for comfort and hot water (Heat)

Cooking is among the most fundamental energy services required by all societies at every stage of development. It is essential to have a reliable source of heat at an appropriate temperature to cook specific items such as grains, meat, fish and vegetables.

In the *poorest, least developed countries,* most cooking is done with firewood, dung, and crop waste that can be gathered by women and children outside of the cash economy. The cooking fire often burns continuously and in cooler regions is a source of space heating and for production of warm water when required. Solar thermal hot water systems are used extensively in countries as diverse as China (the world leader), the United States and Israel. Boiling water to purify it with respect to microbiological contamination requires large amounts of fuel. Far more efficient systems that sterilize drinking water using solar powered ultraviolet light, or that remove bacteria with a ceramic filter as has done introduced in India, Ghana and Honduras are available.

The burning of these poor quality biofuels produce large amounts of harmful particulates that are estimated to contribute to 7 million deaths each year (Montgomery et al, 2009). The black carbon aerosols that are emitted are also a major contributor to global warming, and to the rapid melting of snow and ice fields especially in the Himalayas (Molina et al., 2009).

The utilization of firewood is seldom done on a sustainable basis (IPCC, 2011), and is estimated to be responsible for nearly 12% of deforestation world-wide, and the use of all forms of traditional biomass is estimated to contribute 10% of global warming (IPCC, 2011). This is particularly a problem in rural Africa where it can take half a day or more to gather sufficient fuel because the perimeter of the forest has moved so far from the village because of prior fuel gathering. The gathering of biofuels is a necessity for those living in extreme rural poverty. It is equitable for each family, but the task is borne disproportionately by women and children.

As incomes improve, the conversion of dung, human waste and crop residues into clean burning biogas as is done fairly extensively in rural India and China often at the village level. Also, as incomes rise, people can afford charcoal as a higher quality cooking fuel that is unfortunately produced in a highly wasteful and inefficient manner.

The first shift away from traditional biofuels as economies develop is to cook with propane (a petroleum product), and in urban areas in both economies in transition and developed countries, there is a move to natural gas and electricity, which has major health benefits and reduce deforestation pressures but release large quantities of greenhouse gases.

Lighting, refrigeration, communications and entertainment (Electricity)

Each of these energy services is best supplied by electricity that can be produced by each of the primary energy sources identified in Figure 1. In the following, we will move from least developed to most developed in our discussion.

The electrically supplied energy services required for the *least developed* societies are modest, yet a very small increment in electricity has an enormous impact on the people involved. For these people he greatest need is lighting and communications with a major desire for entertainment. A low cost means of supplying lighting is an integrated solar lantern with bright, efficient light emitting bulbs. This has the advantage of not requiring additional payments for fuel once the device is purchased.

The advent of mobile phones has transformed communications in even poor remote villages. They provide a means of keeping in touch with husbands and sons who have migrated to urban areas for cash employment, they provide farmers with information about weather and market prices for their crops and livestock, handicraft workers with global markets and they provide livelihoods for those who sell phone service to their neighbors. These systems can be readily charged with a small, inexpensive photovoltaic (PV) array.

A slightly larger solar array and a storage battery can supply enough power for two small compact fluorescence lights that allows school children to read their lessons at

night, and a radio that provides both information and entertainment. Increasingly village scale solar systems provide sufficient power for a television set, and perhaps refrigeration for vaccines and medicines at the local health clinic. Such systems have been expanding rapidly in Kenya (Jacobson, 2007) and in Bangladesh (Barua, 2001). Much of the innovation has come from NGOs, who have worked out systems of microloans to purchase these systems, which are paid back from the savings on kerosene and batteries for flashlights and radios, and do not require any payments for fuel.

An alternative technology for off-grid villages is the ubiquitous diesel generator. Most of these run on expensive petroleum based fuels, although it may be possible to grow plant crops locally that produce a diesel-like oil. These machines still require substantial maintenance and are very noisy. They also produce carbon dioxide and black carbon each of which contributes to global warming and the latter, which is a significant local health hazard. It will be decades before many rural areas are electrified from a central power station and the grid is extended to them. Small-scale hydro projects have also been developed in some rural locations in developing countries to supply electricity.

Distributed renewable sources provide needed electrical services for lighting and electrically based services directly to the end user. It can relieve poverty, and can reach the poorest making a large marginal difference on their lives. It does not increase climate change, and does not require the cutting of forests for fuel to generate electricity. It makes individuals and communities more resilient to climate change. Decentralized PV has no effect on biodiversity and does not degrade other ecosystem services. It may be more costly, but the saving in not having to build a grid needs to be taken into account These systems require modest levels of maintenance that can be supplied by local trained residents.

Dwelling scale solar units are also appropriate in grid-connected communities in emerging economies and developed countries as well. Germany currently hosts more than half of the rooftop solar photovoltaic capacity in the world as the result of an aggressive policy initiative over the past 20 years. The author lives in a grid connected solar home in the United States that produces more energy than it consumes for all purposes on an annual basis. Distributed power has the advantage of power generation and utilization at the same site without the losses associated with long-range transmission. It also assures that the power reaches individual users rather than being directed primarily to large industrial customers. Hence there is more equity for individuals than in the case of centralized power.

In emerging economies and developed countries, the preferred model has been a large central electric power plants with an extensive transmission and distribution grid. Electric power may be produced by a very large facility that burns coal or natural gas, or be a nuclear power plant. Coal is the dominant source of electricity in many developed countries, developing countries and emerging economies. There

are also many large hydropower dams in countries at all stages of development including the world's largest, Three Gorges Dam, recently competed in China, and other major installations in Brazil and India. Electric power from dams slightly exceeds the annual electric power production of nuclear plants. Nuclear power requires large complex systems that may exceed the scale and the management capacity of smaller countries. The lesson learned in the United States was that having a single nuclear power plant within a power producing company was ineffective in building the necessary scale of expertise to manage it effectively. Today, nuclear power is concentrated in a few companies each of which has several nuclear power plants. Geothermal power, wind parks and concentrating solar and PV facilities are being developed as well. China now has the largest installed wind capacity having just replaced the United States and Germany in that position. Geothermal heat is used to produce electricity in Costa Rica, Honduras, Kenya, Philippines, United States and Iceland.

As shown in Figure 2, coal produces major amounts of carbon dioxide, while natural gas produces half as much per unit of electricity. Biomass produced electricity is somewhat more complicated to characterize in terms of its emissions. Wood has a higher carbon to energy ratio than coal, and since wood burns at a lower temperature, the efficiency of electricity generation is even lower. As a result, electricity produced from wood is substantially greater than coal at the time of burning. It then takes many years (over 30 in temperate forests) to absorb sufficient carbon dioxide to return the atmosphere to the same level as if coal had been burned instead, and approximately one century before the carbon dioxide released originally has been reabsorbed completely (Manomet, 2010). Since biomass is continuously burned, there is always more carbon dioxide in the atmosphere than there would have been had it not been burned. Cutting trees for power production also destroys forest ecosystems and precludes the provision of many forest ecosystem services such as biodiversity, watershed protection and control of flooding and soil losses. The other primary sources produce very low carbon dioxide emissions – one or two orders of magnitude smaller than fossil fuels.

It is possible to lower carbon dioxide emissions at every stage of development in providing electricity based energy services. Large central power can reach many users especially in urban regions, yet major dam projects and coal plants in many developing countries have gone primarily to industrial users, and there has been little direct benefit to individual people. It is difficult to build grids that reach poor people, and when they are provided there is often significant theft of electric power by individuals. Dwelling scale solar units are also appropriate in grid-connected communities as well. Combined heat and power systems also work very well in a distributed manner since it is possible to capture and use most of the heat that is discarded in large central power plants, which is typically half to two-thirds of the total heat released. Finally, the capital investment in the grid exceeds that of power production sources, so that there are advantages of supplying electricity in a distributed manner.

Smaller distributed renewable systems are modular and can be matched to the scale of individual users and expanded as demand grows. It is therefore more likely to reduce poverty than is the installation of large central power plants especially in the poorest developing countries. These systems also require much less infrastructure and technological capacity. Globally, the electric power sector is the largest source of carbon dioxide emissions (IPCC, 2007).

Agriculture, Manufacturing and Processing, Mechanical Work and Transportation

Providing mechanical work requires a different set of energy pathways to the end user than heat or electricity.

For the poorest rural settings, agriculture and transportation either require human or animal labor. Water for agriculture or household use requires the use of a hand pump, dipping of water buckets or the use of an animal driven "water wheel" or pump. Animals also power plowing and transportation services. These animals also provide dung for solid fuel, biogas and fertilizer, and are fed locally on grass. Weeding and harvesting are done by human labor. This simple energy system operates outside of the cash economy, and despite the relatively low productivity, is self-sustaining as long as sufficient grazing land is available. The agricultural sector is a source not only of carbon dioxide, but also of other greenhouse gases such as methane and nitrous oxide. It is also capable through appropriate management of absorbing and storing carbon from the atmosphere in soils.

In more technologically advanced developing countries, water may be delivered by either a diesel engine pump, a wind driven mechanical pump or by a solar or wind powered electric pump. Animal power for plowing may be replaced by a tractor fueled by gasoline, diesel or biofuel. The biofuel may be grown locally if climate conditions are appropriate, while petroleum based fuels must be constantly purchased from the cash economy. The higher productivity of mechanical devices must generate sufficient cash surpluses to purchase the fuel and maintain the mechanized equipment in order to be sustainable. In emerging and advanced economies, tractors for plowing are supplemented with mechanical harvesting and processing equipment.

Manufacturing and processing equipment is hand operated in the least developed economies, but the addition of electricity either from the grid, a diesel generator or a local wind, solar or local hydro system can substantially enhance the productivity of a carpenter, seamstress, food processer or other modest scale production process. For large-scale production, it is usually necessary to have large sources of electric power to operate motors, and a major heat source for metals, chemicals and other energy intensive industries. These usually involve wither fossil fuels or nuclear power under current circumstances.

Transportation at all levels of development increasingly depends on motor vehicles. In developing countries, there is very little personal vehicle ownership, but small buses serve many riders for hire. Diesel powered trucks move goods in and among all countries regardless of their level of development. In emerging economies, there may be advanced, high-speed rail as in China, Bus Rapid Transit as in Brazil, Colombia and Ecuador and regular rail in many countries. Rail is mostly electrified, but diesel electric locomotives are still in use in many palaces, and very old coal based steam engines are still used in a few countries. Motor scooters are common in many countries as are motorized "rickshaws." Attempts to electrify the latter to deduce air pollution have not been successful in countries such as Nepal. Bicycles were once common in large Chinese cities, but have largely disappeared. However, bicycles are used in both developed (Netherlands) and developing countries (small Chinese cities) for local urban transportation. Petroleum based fuels dominate transportation in all countries except Brazil, where a highly successful bioethanol effort now supports nearly half of all spark ignition engines. European countries have made a major effort to create biodiesel from a variety of plants, but this has lead to the destruction of forests in Malaysia and Indonesia that have been cleared for palm oil plantations. Air and ship transport of people and goods is entirely fueled with petroleum-based products. The transportation sector has introduced hybrid electric-gasoline hybrids, plug-in hybrids and all electric vehicles in developed countries in order to extend range, improve performance and reduce carbon dioxide emissions.

The current heavy dependence on petroleum based fuels for transportation creates major economic problems for many countries. Oil importing nations are required to pay in hard currency, which then limits their options for development. Nearly two-thirds of oil reserves lie in the Middle East, and a major reduction in the use of oil-based products would have major adverse repercussions for the economies of oil producing nations. The transportation sector is the most rapidly growing source of carbon dioxide emissions (IPCC, 2007).

5. Policies

A comprehensive analysis of policies to implement renewable (low carbon) energy is provided in the IPCC Special Report on Renewable Energy (Chapters 1 and 11) (IPCC, 2011) that identifies opportunities, barriers and issues and describes the policies that might best overcome the barriers. A table from that report is reproduced below as Table 2, and forms the basis for the discussion in this section.

Type of barrier	Some potential policy instruments
Market failures and economic barriers • Cost barriers • Financial risk • Allocation of government financial support • Trade barriers	Public Support for renewable energy (low carbon) research and development; policies that support private investment, including fiscal incentives; public finance and regulatory mechanisms (e.g., Feed in tariffs, quotas, use standards)
Information and awareness barriers • Deficient data and natural resources • Skilled human resources (capacity) • Public and institutional awareness	Resource assessment; energy standards, green labelling; public procurement; information campaigns; education, training and capacity building
Institutional and policy barriers • Existing infrastructure and energy market regulation • Intellectual property • Industry structure	Enabling environment for innovation; economic regulation to enable access to networks and markets and investment in infrastructure; revised technical regulations, international support for technology transfer (e.g., under the UNFCCC), microfinance; technical training
Issues Relevant to policy • Social acceptance	Information campaign; community projects; public procurement; governmental (national and local) policy cooperation; improved processes for land use planning

Table 2. Barriers and classes of policies to address them (IPCC, 2011).

Because the energy service needs are so different for societies at different stages of development, the policies needed to implement alternative low carbon fuels to supply those services will also differ. The policies will therefore be organized in terms of the four stages of development described in Section 3.

Least Developed Countries

Least developed countries are in need of the most basic energy services, and these are most likely to be supplied by international donors and NGOs.

- Improving cooking services should be a primary goal, and the introduction of improved stoves and solar cookers needs to be implemented in collaboration with users to avoid the "cook stove introduction failures" of the past. Government policies that would create local manufacturing or assembly of these improved cooking devices could be implemented to create local livelihoods. Policies for the development of biogas digesters to fuel cleaner cooking have been very successful in rural India, China and other parts of Asia.

- Examples such as solar powered lanterns, radios and mobile phone chargers have been successfully been sold to replace kerosene lamps and flashlight batteries in the poorest countries such as Haiti by NGOs. More extensive solar systems have similarly been sold in Bangladesh to hundreds of thousands of rural households also by an NGO. The least developed countries could assist this process by establishing policies that set targets and timetables for assuring access to a set of basic energy services. Governments could then work with NGOs and international banks and bilateral aid agencies to provide the basic low carbon technologies and develop a national strategy for assuring their universal distribution. This "micro-energy" approach might be accelerated by the utilization of micro-finance. As the availability of energy services becomes more wide spread, policies described for developing countries could be implemented.
- Creating electricity services for urban areas requires government policies to provide both distributed sources of power such as solar panels instead of diesel generators as well as the development of larger power stations such as hydro or geothermal power. Successful examples of this include small hydro and geothermal projects in countries such as Honduras and Kenya. These projects require that governments work with international aid agencies.
- Providing subsidies for low carbon technologies or fuels and creating an effective distribution system for them are major policy initiative that would effect this transition.
- The most important policy actions that governments of the least developed countries can establish are those that build capacity. The training and support of "barefoot technicians" who can support the introduction of clean stoves, teach local villagers how to build biogas and locally grown biofuels and introduce and maintain solar PV technology is a critical role that governments can play.

Developing Countries

Developing country needs are for more extensive low carbon electrification of services in rapidly growing urban regions while still meeting the needs of rural users. The policy steps for the least developed countries will need to be implemented alongside the development of larger scale low-carbon projects. Unfortunately, the policy approach in most developing countries is simply supply-push rather than considering the most effective low carbon means for delivering energy services. In this they are often supported by international banks and aid organizations. There are some notable exceptions that provide useful examples.

- South Africa has established policies to utilize more renewable energy for electrically powered energy services and for solar hot water, and. The World Bank is working with South Africa to build Africa's largest wind and solar electricity projects.

- Smaller developing countries such as Honduras and El Salvador have developed renewable energy projects through the Clean Development Mechanism of the Kyoto Protocol. Policies that encourage this sort of international cooperation would accelerate the transition to low carbon alternatives.
- Kenya and Philippines have policies that have successfully developed geothermal power with international assistance.
- Removing subsidies for fossil fuels is an important policy action needed in many developing countries.
- Not all renewable energy projects are, however, low carbon. The cutting of rainforests in Malaysia and in Indonesia to create palm oil plantations to supply the demand for biofuels in Europe has lead to major in creation of large increases in carbon dioxide and a reduction in the capacity of forests to absorb carbon dioxide. Policies to limit this practice are essential.
- The FAO and other international organizations have called for policies to halt the production of biofuels that compete with food production.
- The potential for the REDD+ agreement to reduce deforestation is a significant international policy that over thirty developing and least developed countries may join that needs to be accompanied by policies to meet heating and cooking services in a low carbon way.

Emerging Economies

The policy needs of emerging economies are similar to those for developed countries. Financial as well as regulatory policies have proven effective in moving to low carbon technologies for delivering energy services. These countries have the capacity to manufacture and install major low carbon technologies, and have policies in place to encourage those industries. This section is organized in terms of three major emerging economies to illustrate what types of policies are utilized.

- India has developed a number of major low carbon initiatives mostly through setting goals with Five year Plans and having a centralized system for implementing specific projects.
    - India has a Ministry of New and Renewable Energy that establishes specific project goals and has a national mandate to expand renewable energy.
    - The Asia Development Bank is working with this ministry to develop over 5 MW of solar electricity capacity in India.
    - Because of policies to meet goals for installation of renewable energy, India is now a global scale producer of wind turbines and solar PV panels.
    - India also has policies that encourage the development of nuclear power, although this still represents a small portion of national electricity.

- India has developed an extensive amount of major hydropower projects using mandates to develop them.
- India has relaxed regulations on business initiatives and high tech companies have flourished.

- China has had the greatest growth in low carbon energy technologies during the past decade and now leads the world in many of them. It has financed major research and development and specific technologies. At the same time its use of coal continues to grow, but its carbon intensity is dropping. China establishes energy intensity and other goals through Five Year Plans and then sets specific policy mandates.
  - China established major policies that set goals for installing wind turbines, and within 5 years became the world leader in installed wind capacity.
  - China is also the world leader in the manufacturer of PV panels as the result of direct payments to establish domestic manufacturers. China mandates solar hot water panels on all new apartment buildings.
  - Chinese policy on hydropower has made it the largest producer of hydropower in the world, and its nuclear policy is leading it to build a large number of these plants as well.
  - China may be the only government that is taking old, inefficient coal power plants put of service, and is building the world's most efficient coal plants. They are also at the forefront in building the first large-scale CCS project for a new coal power station.
  - The rapid growth in vehicles that rely on high carbon petroleum for fuel is being addressed in part my mandating very high fuel economy standards and mandates to produce large numbers of electric and hybrid electric vehicles in the next few years.
  - China is expanding its regular and high-speed rail system extremely rapidly.

- Brazil has relied on support for research and setting policy mandates.
  - Brazil developed bioethanol from sugar cane for transportation fuel over the past four decades. Currently more than 40% of vehicle miles are traveled on this low carbon option. There were mandatory policies to integrate bioethanol into the fuel mix of the country. They are exploring other potential biofuel options as well.
  - Brazil has directed policies to develop extensive hydro projects that produce over 80% of the country's electric power, and make it the third largest hydro country in the world. These projects are controversial in that they destroy forests and release methane into the atmosphere.

Developed Countries

Developed countries have well-developed energy systems that varies enormously in terms of carbon intensity. This presents a challenge since there is so much of the energy system that is "locked-in" to existing high carbon infrastructure. All developed countries have large petroleum consuming vehicle fleets. Developed countries utilize financial incentives, regulations and non-regulatory measures.

- Financial incentives

  - Carbon taxes are utilized in a number of European countries to raise the cost of high carbon fuels. In addition there have traditionally been high fuels taxes for vehicles that further raise the cost of these fuels
  - Subsidies are utilized for renewable energy including feed-in tariffs for electricity that pay a premium for renewably generated low carbon electricity
  - Remove subsidies from fossil fuels
  - Established preferred interest rates on borrowing for investment in low carbon options
  - Emissions trading is used under a cap and trade system that decreases the amount of carbon permitted to be released each year. The largest system is that of the European Emissions Trading System, which began in 2005. A regional system, Regional Greenhouse Gas Initiative, for 10 Northeastern states in the United States has been underway beginning in 2006
  - Governmental support of research and development is provided by some governments, especially the United States
  - Governmental procurement of low carbon fuels and technologies

- Regulatory policies

  - Establish energy and carbon performance standards for power production and vehicles
  - Establish low carbon quotas or goals such as renewable portfolio standards
  - Remove barriers to innovation such as restrictions on distributed generation or maximum amounts of renewable energy on the grid
  - Develop grid infrastructure for maximum effective use of variable renewable technologies and for load management
  - Establish clear interconnection rules for power grids and ensure that they encourage the use of efficient low carbon technologies

- Non-regulatory policies
    - Provide education and training in engineering and policy
    - Provide assessments of low carbon resources
    - Provide information including appropriate labeling of products and energy sources with their carbon intensity and other environmental impacts
    - Establish certification standards and processes either through governmental policies or through third party organizations

The relative merit of each of these policy instruments varies with region and stage of development.

6. Criteria

Any specific policy action is likely to have multiple effects, and it may work well in some respects while performing poorly on other dimensions. Systematic application of the approach also may allow policy makers to determine if a policy would lead to conflicts or synergies across criteria that might alter the desirability of a particular course of action. The MCA4climate approach has laid out a suite of general criteria categories that national governments can apply to each theme area to guide their climate change mitigation and adaptation planning. These are systematically structured across three different levels, going from general to specific, as displayed in Figure 5.

The MCA4 Climate process has identified 19 criteria for evaluating policies and actions. These are divided into Inputs and Outputs, and are organized in the manner below. Many of the specific implications for policies are included in the examples of the previous section. For a more detailed discussion of the criteria tree at the generic level displayed in Figure 5, see the main MCA4climate report and other documents available on www.mca4climate.info. The aim of this section is to further elaborate on the level-3 criteria and how they may be applied to the mitigation theme of increase the share of low-carbon energy sources in the fuel mix. The respective criteria and indicators will vary in their relevance depending on the type of country being applied to (least developed, developing, emerging, and developed).

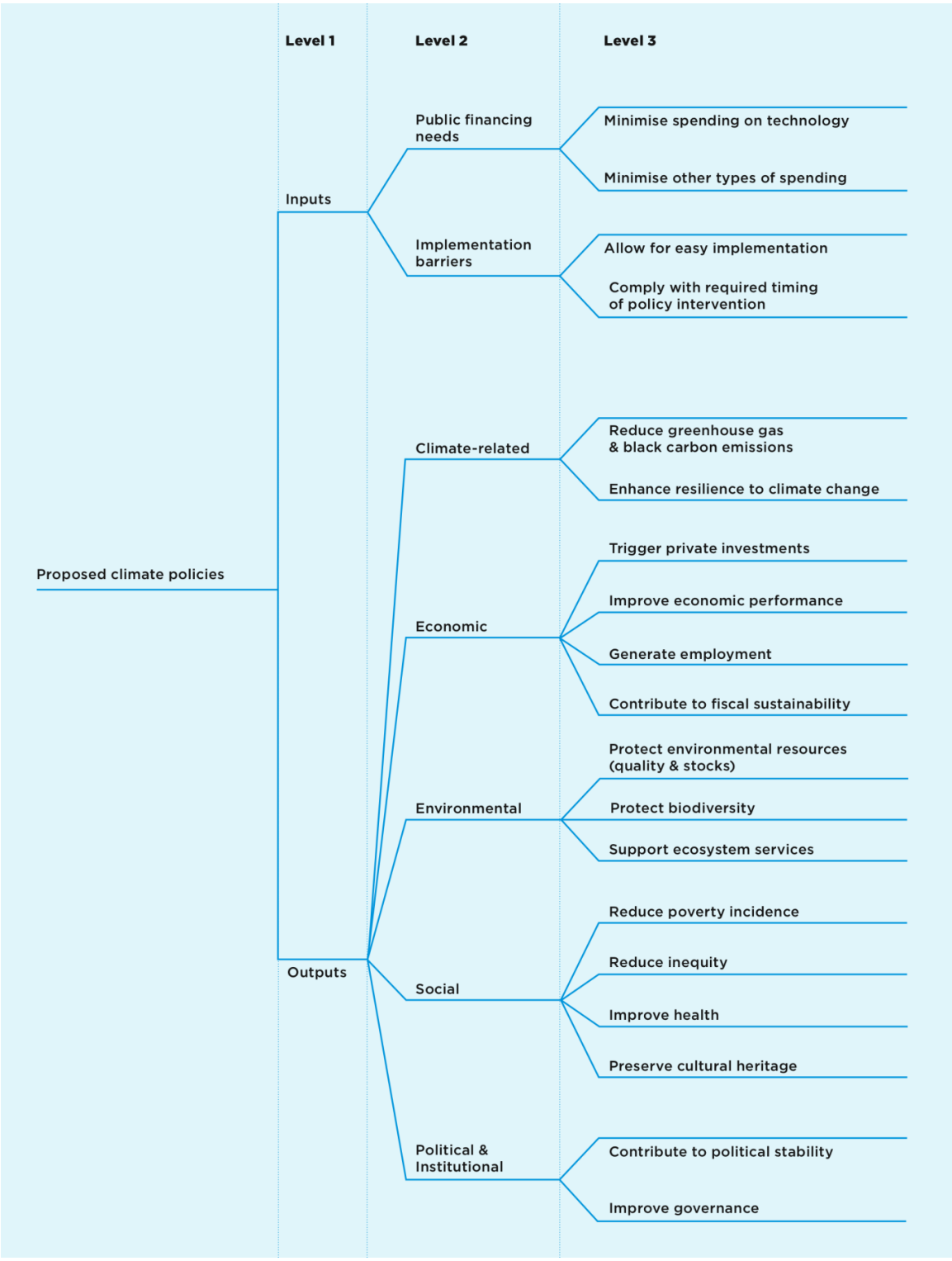

Figure 5: The generic criteria tree, part of the MCA4climate policy evaluation framework

Inputs

Public financing needs

Minimize spending on technology
The three groups of developing countries are at the early stage of building their technical infrastructure and expenditures for low carbon options can be part of the ongoing development costs. If the energy services perspective is selected, then the amount of new energy supply will in most cases be less than if traditional supply push energy planning is followed. Hence the costs need not be greater to pay for low carbon options, but if it is, international donors could make up this difference. The marginal increase is likely to be small relative to the cost of additional climate change. For developed countries that already have much of their energy infrastructure, it will be necessary to utilize natural capital turn over as the time to make investments.
Indicators – Expenditures in terms of spending per unit of low carbon energy

Minimize other types of spending
There are often co-benefits that accrue by using alternative sources of energy to deliver energy services. Improved air quality and health benefits can be substantial as when eliminating black carbon.
Indicator – Reduction in need for additional expenditures for emission controls

Implementation barriers

Allow for easy implementation
Implementation barriers are summarized in Table 2 and a summary of policy types is provided in that table. Policy feasibility is a function of existing interests, economic costs, availability of financing and the capacity of a society to manage and operate specific technologies. The examples from specific countries in part 6 demonstrate that policy implementation is feasible under a variety of circumstances.
Indicator – Listing of policies actually implemented and a periodic assessment of their effectiveness

Comply with required timing of policy implementation
To be effective, policies need to be consistent over a long time horizon. The success of feed-in tariffs in Europe is in part because a buyer of renewable energy technology was assured of a known higher payment for electricity generated for a specified period of time. Time is also important in giving sufficient notice of a change in rules so that the goal can be met in practice.
Indicator – The extent and timing of adoption of policies are measure of the success of implementation. The length of time taken to implement policies is another.

Outputs

Climate-related

Reduce greenhouse gas & black carbon emission
The effectiveness of policies in reducing greenhouse gas and black carbon emissions is relatively easy to measure if a proper reporting system of energy use is developed. For example, the replacement of traditional biomass stoves with clean biogas or solar cookers can be immediately seen by the users and any inspector. The replacement of fossil fuels with renewable or other means of providing energy services can be noted in national energy use figures.
Indicator – Tracking number of stoves replaced and the shift in primary energy use is sufficient to tell if the policies to induce these changes have been effective.

Enhance resilience to climate change
Shifting fuels from carbon intensive fossil fuels to low carbon alternatives may affect resilience to climate change particularly if the alternative such as wind and solar uses less water than a thermally cooled power plant. Hydro dams may be able to store water for drought conditions increasing resilience. Replacing traditional biomass with biogas may provide a fuel source when drought reduces biomass productivity.
Indicator – Need to examine each case independently and identify a specific variable to determine whether it has increased resilience to climate change.

Economic

Trigger private investments
Policies that require a shift to low carbon technologies and fuels can provide opportunities for private investment to meet an assured market. This has been demonstrated in both developed countries and in emerging economies (See Section 6)
Indicator – Track private investment in alternative energy supply over time

Improve economic performance
The introduction of new energy services in the least developed countries can show a significant improvement in economic wellbeing in a very short time. As economies develop, the contribution of any single technology is a smaller share of the growth of the entire economy. It is necessary to monitor the gains over time. The example of the rapid growth of low carbon energy to the Chinese economy has been particularly striking. They have not only developed these technologies for domestic use, but for export markets as well.
Indicator – Measure economic change and correlating it with specific energy sectors

Generate employment
Observing the jobs created in specific industries as they grow demonstrates that the shift to low carbon energy supplies does create jobs in countries like Denmark, Germany, India and China.
Indicator – Measure jobs in specific industries over time

Contribute to fiscal stability
The very heavy dependence on a mal-distributed energy source such as petroleum has lead to very large and unpredictable swings in price that have been particularly damaging to developing economies. Diversifying sources of supply reduces this vulnerability and the utilization of local renewable sources can increase energy and economic security as well.
Indicator – The price of energy services over time compared to earlier times that were reliant on fossil fuel sources will determine the extent to which alternative low carbon energy has lead to fiscal stability

Environmental

Protect environmental resources (quality & stocks)
As demonstrated in Figure 4, most low carbon renewable energy sources have much less impact on the environment. As long as the rate of use of the resource is less than the rate of production, the stocks will not be depleted, and the quality of the resource will be maintained.
Indicator – Most renewable sources of energy deliver energy services with less environmental impact than does the process of extracting and burning fossil fuels as is indicated by impacts on land, water and air

Protect biodiversity
Most of the alternative sources have less impact on biodiversity because the do not affect the climate system or because their direct environmental impact is less. The one exception is biomass because the cutting of forests for fuel wood degrades forest ecosystems.
Indicator - Monitoring biodiversity for changes arising from fuel extraction, use or energy production

Support ecosystem services
Renewable energy is the extraction of an ecosystem service. As indicated, biomass extraction can degrade ecosystem services such as biodiversity, and energy plantations can displace major natural and agricultural ecosystems. The use of solar energy, does not affect the amount flowing to the earth from the sun and the amount available exceeds all human energy uses by several thousand-fold. Extracting energy from hydropower dams can disrupt major riverine ecosystems. Wind and geothermal resources will not affect most ecosystem services at any anticipated levels.

Indicator – All energy use has an adverse effect on ecosystem services, but most low carbon systems have lower impacts than do high carbon fuel use.

Social

Reduce poverty incidence
Especially for the least developed countries, the addition of low carbon, renewable energy technology begins to lift people out of poverty. Additional capacity provided for those in developing countries increasingly provides additional energy services that reduce the incidence of poverty. People at these levels cannot afford the continuous drain of their limited cash resources that reliance on fossil fuels requires.
Indicator – Evaluating how specific individuals or villages that have obtained these technologies are faring economically

Reduce inequality
By reducing poverty, more people move into a higher wealth category thereby reducing inequality. These technologies also reduce inequality because they can be distributed universally, and free people from the continued burden of paying to fuel their energy services.

Improve health
As indicated earlier, eliminating the burning of biomass for cooking, purifying water and providing heat has a major improvement on improving people's health. In a larger setting, reducing the use of coal-fired power plants also reduces particulates, and avoiding all combustion with alternative technologies reduces lung damaging from ozone.
Indicator – Improved health status where alternative technologies are utilized

Preserve cultural heritage
Providing modern energy services may not preserve cultural heritage, but they can certainly improve the well being of the poorest people

Political & Institutional

Contribute to political stability
Having basic energy services allows people to meet many basic needs, which is likely to promote political stability. However, the use of social media can disrupt political stability if the public does not feel that its interests are being served.
Indicator – Evaluate and compare regions with and without electricity based energy services including communications technology

Improve governance
The availability of more energy services will permit additional citizens to participate in governance. Improved communication services will also promote political stability by allowing the government to provide information services and to communicate with more people. Media can also improve people's knowledge and understanding of political events.
Indicator – Studies of how people effective governance is in regions with and without these energy services that would otherwise not be implemented without renewable energy

7. Conclusions

Delivering energy services to end users can take multiple paths, each of which requires a different amount and source of primary energy. Combustion of fossil fuels releases carbon dioxide to the atmosphere, so that the best way to reduce emissions is to utilize alternative options such as wind, solar, hydro, geothermal, and oceans.

Biomass can be locally collected at no cost other than the labor of gathering it. It is a very equitable source of primary energy that is well suited to many needs of poor rural economies. It doers, however release significant amounts of carbon dioxide when burned, which can be recouped only over a =relatively long period of time *if* there is replanting. Rapidly growing plants can produce fuels that have relatively small net emissions if they are replanted to reabsorb carbon dioxide (Manomet, 2010). Most traditional biomass is not sustainably managed, and contributes to climate change (IPCC, 2011). The cutting of forests for fuel reduces the capacity of the forest to provide a variety of ecosystem services including biodiversity, watershed protection, water quality and other goods and services.

The social implications of alternative fuels used to supply the energy services depend upon the state of development of a particular society. In the poorest societies, where gaining access to grid-supplied electricity is many years off, distributed solar PV electricity can meet most needs. This source is simple, reliable and can be cost competitive with the kerosene lamps and disposable batteries that they replace. This source has an advantage in that it brings electricity directly to individual users, and can be scaled up to the village level. The system can be put in place by NGOs and need not wait for governmental action. It can be put in place in such a way as to meet equity concerns. It does not require water, large amounts of land, produce air or water pollution or damage biodiversity. There is no need for ongoing purchase of fuel.

Other low-carbon, localized distributed sources such as wind turbines, small-scale hydro and concentrating solar power require more capital and capacity to operate a complex system. Diesel generators or direct drive motors are common, but require maintenance and a constant supply of fuel that must be purchased.

Distributed renewable systems can meet many needs, but are variable in nature and need to be used in combinations with each other and with fuels such as natural gas or with hydropower. If electric drive vehicles begin to take on larger share of the market as China and other countries are attempting to do, then their batteries become a storage device for variable output sources. This would also remove a major source of carbon dioxide emissions from the combustion of oil-based fuels.

For large-scale industrial production, larger, higher energy density sources are often needed. Hydro and nuclear power meets this criterion as do conventional fossil fuels, but only the first two are low-carbon.

8. References

Ackerman, F., (2009), Can We Afford the Future. The Economics of a Warming World. Zed Books, London.

Barua, D.C., T.P. Urmee, S. Kumar, and S.C. Bhattachary (2001). A photovoltaic solar home system dissemination model. Progress in Photovoltaics: Research and Applications, 9(4), pp. 313-322.

Bazilian, Morgan, P. Nussbaumer, A. Cabraal, R. Centurelli, R. Detchon, D. Gielen, H. Rogner, M. Howells, H. McMahon, V. Modi, N. Nakicenovic, B. O'Gallachoir, M. Radka, K.Rijal, M. Takada, F. Ziegler (2010). Measuring Energy Access: Supporting a Global Target. New York: United Nations and the Earth Institute at Columbia University.

Boden, T., and G. Marland (2010). Oak Ridge National Laboratory, Carbon Dioxide Information Analysis Center.

IPCC (2007). *Climate Change 2007: Mitigation of Climate Change. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds.)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 851pp.

IPCC, (2011). IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Jacobson, Arne, (2007). Connective Power: Solar Electrification and social Change in Kenya, World Development Vol. 35, No. 1, pp. 144–162.

Jacobson, M. (2009). Review of solutions to global warming, air pollution, and energy security. *Energy and Environmental Science*, 2, pp. 148-173.

Molina, Mario, Durwood Zaelke, K. Madhava Sarmac, Stephen O. Andersend, Veerabhadran Ramanathane, and Donald Kaniaruf (2009). "Reducing abrupt climate change risk using the Montreal Protocol and other regulatory actions to complement cuts in CO2 emissions" *Proceedings National Academy of Sciences*, 106, pp.20616-20621; doi:10.1073/pnas.0902568106.

Manomet Study of Woody Biomass Energy, (2010). A report prepared for the Commonwealth of Massachusetts. Accessed at http://www.manomet.org/

Montgomery, David, Robert E. Baron and Sugandha D. Tuladhar. 2009. "An Analysis of Black Carbon Mitigation as a Response to Climate Change." Washington, DC: Copenhagen Consensus on Climate.

Moomaw, W., M. Papa, (2011). Can universal clean energy services create a mutual gains climate regime? Working Paper, Center for International Environment and Resource Policy, http://fletcher.tufts.edu/ierp/ Submitted for publication.

Sovacool, B. (2008). Valuing the emissions from nuclear power: a critical survey. *Energy Policy*, **26**, pp. 2940-2953.

Stern, N.H. (2006). The economics of climate change: Stern review on the economics of climate change. HM Treasury, England, ix, 579 p.

United Nations Department of Economic and Social Affairs (UN/DESA). (2009). World Economic and Social Survey 2009: Promoting Development, Saving the Planet, E/2009/50/Rev.1ST/ESA/319. Available at http://www.un.org/esa/policy/wess/wess2009files/wess09/chapter2.pdf

Weisser, D. (2007). A guide to life-cycle greenhouse gas (GHG) emissions from electric supply technologies. *Energy*, **32**, pp. 1543-1559.