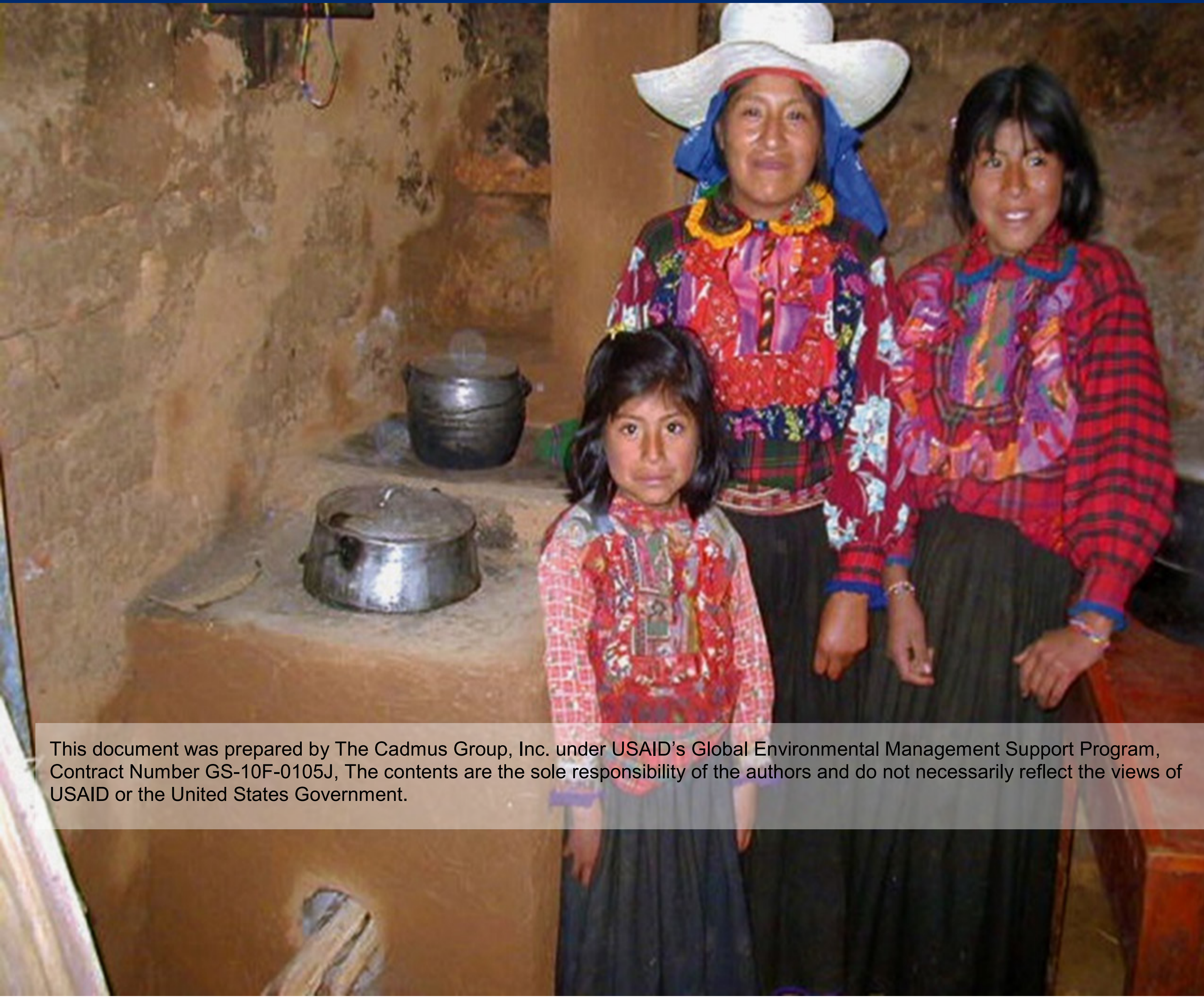
ENVIRONMENTALLY SOUND DESIGN (ESD) SECTOR ENVIROMENTAL GUIDELINES

SMALL-SCALE ENERGY

Partial Update May 2018 | Last Full Update: Prior to 2003



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Cover Photo: A mother and her children pose alongside a biomass cookstove in Peru. Photo Credit: Winrock International.

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ABOUT THESE GUIDELINES

Experience has shown that following environmentally sound design (ESD) principles in planning and carrying out new small-scale projects and programs helps people to avoid potentially costly mistakes and often makes development activities more sustainable over the long run.

The *ESD Sector-Specific Guidelines* are USAID's principal source of sector-specific environmental guidance. For each development sector addressed, the Guidelines brief the potential, typical adverse impacts for activities in this sector; provide environmental good practice guidance for sector program design, environmental mitigation and monitoring guidance; and include an annotated bibliography of web-accessible resources.

The first edition of the Guidelines was published in 1996. For the second edition, the Guidelines were completely updated and expanded. The current third edition has been edited to adopt a global perspective and integrate relevant technical content and sectoral examples from USAID's Asia/Near East and Latin America and the Caribbean versions of the guidelines and is a work in progress. Modules are updated and new modules added on a rolling basis.

These Guidelines include annotated bibliographies of the most useful source materials. In each case, we have emphasized materials available via the Internet. The online version of the Guidelines at www.usaidgems.org contains HTML links to these sources, while the CD-ROM version of the Web site contains both the Guidelines and much of this source material. We therefore hope that development practitioners will be able to quickly find and consult extensive practical sources on specific sectors.

Because ESD for small-scale activities requires the people responsible to understand ESD principles and integrate them into project design and implementation, it cannot and should not be the exclusive concern of environmental professionals. We have therefore worked to keep the language of the Guidelines as straightforward and free of technical jargon as possible.

The development of the Guidelines was funded by USAID to meet the needs of its staff and its partner organizations. However, they are broadly applicable to other donors; community-based and non-governmental organizations; local governments; and others engaged in small-scale activities.

NOTE: The Guidelines are advisory only. They are not official USAID regulatory guidance or policy. Following the practices and approaches outlined in the Guidelines does not assure compliance with USAID Environmental Procedures or host country environmental requirements.

LIST OF ACRONYMS

ABPP	Africa Biogas Partnership Programme
AC	Alternating Current
AC	Air Conditioning
APU	Auxiliary Power Unit
BMZ	German Ministry for Economic Cooperation and Development
BOS	Balance-of-system
C	Construction
CCS	Carbon Capture and Storage
CHP	Combined Heat and Power
CO2	Carbon Dioxide
CT	Combustion Turbine
DC	Direct Current
DCM	Decommissioning
DER	Distributed Energy Resources
DOE	Department of Energy
EA	Environmental Assessment
EIA	Environmental Impact Assessment
EMMP	Environmental Mitigation and Monitoring Plan
ESD	Environmentally Sound Design
ESDM	Environmentally Sound Design and Management
EU	European Union
GACC	Global Alliance for Clean Cookstoves
GHG	Greenhouse Gas
GWth	Gigwatts Thermal
IC	Internal Combustion
IEA	International Energy Agency
IP	Implementing Partner
kW	Kilowatt
kWh	Kilowatt Hour
LCOE	Levelized Cost of Electricity

LPG	Liquefied Petroleum Gas
MSW	Municipal Solid Waste
MW	Megawatt
NGO	Non-governmental Organization
NOx	Nitrogen Oxides
NREL	National Renewable Energy Laboratory
ODC	Oserian Development Co. Ltd.
OECD	Organisation for Economic Cooperation and Development
O&M	Operation and Maintenance
PM	Particulate Matter
POME	Palm Oil Mill Effluent
PPE	Personal Protective Equipment
P&D	Planning and Design
PV	Photovoltaic
RoR	Run-of-the-River
SO2	Sulfur Dioxide
UPS	Uninterrupted Power Supplies
USAID	United States Agency for International Development
VOCs	Volatile Organic Compounds
W	Watt
WEO	World Energy Outlook

SMALL-SCALE ENERGY

Energy is at the core of economic growth in both industrialized economies and in the developing world, but the continuation of current trends in energy usage is not sustainable.

A micro-hydro power station located in Chitral in northern Pakistan. Photo Credit: Winrock International.

INTRODUCTION

The depletion of non-renewable resources (i.e. fossil fuels), the global impacts of energy production on natural systems, climate change, the rising costs for conventional energy (especially oil), and demands for energy security are driving investments in energy efficiency, renewable energy, and clean energy technology. How we supply and use energy not only affects the bio-physical environment, but also human health and economic wellbeing. According to the World Energy Outlook 2012 *New Policies Scenario*, global energy demand is predicted to grow by more than one-third through 2035, and has more than doubled in about 40 years (see charts below).

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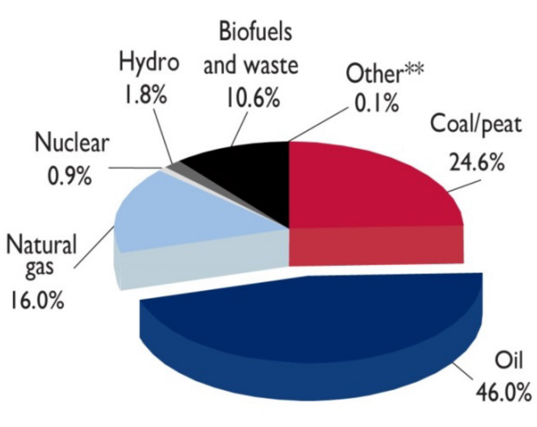

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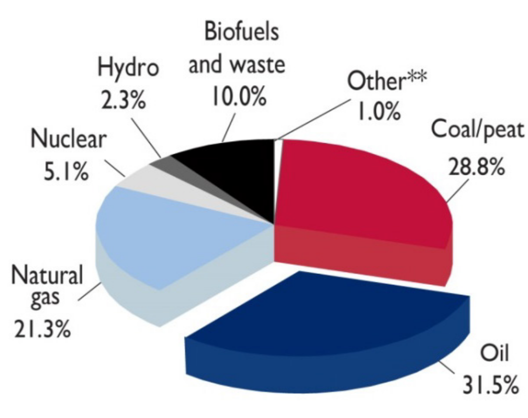

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Renewable energy can have numerous benefits, such as increased energy access in developing countries, public health improvements, climate change mitigation, etc. However, for those benefits to be realized, several sustainability considerations must be addressed in the design. **Project barriers**, such as cost, host-country regulations, ethical and effective governance, and challenges that arise during project operation must be reconciled. Project managers must have accurate knowledge of energy alternatives and their **relative costs and benefits** from an economic, social, and environmental perspective. Incentives such as subsidies and tariffs can shift both supply and demand toward more sustainable energy and economic practices. Government, private, or NGO funding can likewise stimulate renewable energy development. **Long-term commitments to regular maintenance** and **monitoring** must be established **during project design** to ensure effectiveness. Associated **long-term recurrent costs** must also be determined and budgeted prior to project initiation, including the sustainability of a project after NGO, donor, or government support ends.

This guideline is ultimately intended to inform developers and implementers of small-scale energy projects about environmentally sound design (ESD). Distinguishing "small-scale activities" from not small-scale ones is subjective. In this document, the definition will be considered to include, but not be limited to, households or individual or cooperative farms; community-level projects; micro- and small enterprises; and institutional projects such as schools, health clinics, and hospitals.

By contrast, large-scale commercial power plants (i.e. those larger than 10 megawatts [MW]) are not covered in this guideline, nor are large-scale hydro (>10 MW), wind (>1 MW turbines), solar (>20 kilowatts [kW]), geothermal, or bioenergy projects (>10 MW). Other energy systems not covered by this guideline include natural gas production from hydraulic fracturing and hybrid diesel/renewables systems. The impacts of transmission lines on viewsheds (the natural environment visible from a certain viewing point), wildlife, or vegetation are not included in this guideline.

This guideline focuses on various renewable energy resources and systems, but also describes fossil fuels and systems that support small-scale activities. Solar power, small hydropower, wind power, geothermal energy, and bioenergy are all discussed with an overview of the recent trends and technological applications, with emphasis given to their potential environmental impacts and sound environmental design and management (ESDM) techniques, including effective mitigation and monitoring measures for use throughout project implementation.

It is especially important that the process of assessing potential impacts occurs as early in the design stage as possible. This includes properly weighing feasible project alternatives and considering how best to avoid or minimize potential adverse energy-related and environmental impacts. The guideline also emphasizes the potential for _*cumulative*_ environmental effects from multiple small-scale energy activities, discusses the risks small-scale energy projects face as a result of global climate change, and provides general information on the economics and gender impacts of small-scale energy projects.

The environmental impacts discussed in this guideline apply to the overall **life cycle of the activity** from **"cradle to grave"**[1] and include **indirect effects** (e.g. the sources of energy and materials for the manufacture of wind and solar systems, or the impacts of constructing roads to serve small-hydro facilities). The overall impacts from each phase of an activity need to be considered: mining and materials extraction; processing and manufacturing; construction, operation and maintenance; and finally, decommissioning (e.g. disposal at end of useful life). **Even small-scale projects may require environmental assessments (EAs)** when they have potentially significant impacts on sensitive ecological, cultural, or archeological resources, or could potentially degrade biodiversity, natural forests, or protected areas or create impacts on ecosystem goods and services. Ecosystem goods and services are the many benefits that ecosystems provide to people, such as water supply, carbon sequestration, flood risk reduction, and cultural value.

[1] For example, impacts include the final disposition of batteries from wind and solar systems, or the decommissioning of biogas systems or wind towers at the end of their engineered design lives.

If significant impacts are expected, the planning and design process could include an ecosystem services valuation (ESV) as part of the predevelopment assessment. An ESV will help decision makers understand how projects depend on and impact ecosystem services. This understanding can help communities realize the trade-offs associated with development and management of different kinds of energy projects. An ESV informs decisions that can minimize and mitigate a project's most harmful effects. For more information about applying an ecosystem services framework to the Environmental Impact Assessment process, see USAID's Environmental Compliance Factsheet: Ecosystem Services in the Environmental Impact Process."

The environmental impacts for each energy source in this guideline are presented in a table at the end of the section, which also includes associated mitigation and monitoring measures for each impact identified. These mitigation and monitoring measures are designated according to the project phase(s) where they best apply: Planning and design (P&D), Construction (C), Operation and Maintenance (O&M), and Decommissioning (DCM). **The environmental impact tables are intended as *guidance* to inform the development of project-specific mitigation and monitoring plans prior to project implementation**. Templates for project-specific mitigation and monitoring plans are included as an annex to this guideline. These plans add essential elements beyond the mitigation and monitoring measures, such as identifying responsible parties for each action, designating the timing of those actions, and making budget allocation(s) for the required mitigation and monitoring actions.

The tools and technologies available to optimize energy resource management, optimize energy efficiency, and minimize potential environmental impacts in the developing world are significant. From night lighting with photovoltaic technology to community electrification with wind power, renewable energy technologies have the potential to improve the living standards of even the most rural, remote communities. Although renewable energy activities often have fewer environmental impacts than fossil fuels or nuclear power, they nevertheless have the potential for adverse environmental effects that should be mitigated and monitored. While renewable energy projects are becoming increasingly more common, many small-scale development activities remain dependent on fossil fuels, requiring attention to minimizing or eliminating their potential adverse impacts as well. Through the use of ESDM techniques, small-scale energy projects have the greatest chance of affecting sustainable positive environmental impact.

SOLAR ENERGY

Solar energy is becoming an increasingly popular option throughout the developing world. Photovoltaic (PV) generation (pictured at left) represents one of the many ways solar energy is utilized for small-scale applications.

Photo credit: Scott Gruber, USAID.

OVERVIEW

This guideline addresses the use of solar energy for heating, hot water, lighting, cooking, water purification, and electricity. Solar technologies include a variety of specific technologies, including photovoltaics (PV) and several types of solar thermal systems, as described in this guideline. These technologies are especially useful in developing countries because many such locations rely on expensive, unreliable, and/or environmentally-harmful fuel sources, such as solid biomass and oil. Solar energy offers a low-operation and low-maintenance cost solution and is a realistic option in developing countries as many are located in areas with high solar radiation averages. Some solar technologies, such as solar cookers, can also be constructed and maintained locally, providing a potentially self-sustaining revenue stream. For the purpose of this guideline, small-scale solar projects are those with up to 20 kW of rated direct current (DC) output, although small-scale solar systems are typically much smaller.

TRENDS AND ECONOMICS

Photovoltaics

While large potential for PV energy technology exists, conventional solar grids and even micro-grids have been considered unrealistic for rural households because of their high cost and the difficulty in accessing materials. However, solar PV is currently the fastest growing source of renewable energy around the world, albeit from a small base (see the *REN 21: Renewables 2013 Global Status Report*). In Organisation for Economic Co-operation and Development (OECD) countries, the market is dominated by large solar farms and rooftop projects

DID YOU KNOW…

All of Earth's energy stored in coal, oil, and natural gas reserves is matched by the energy from only 20 days of sunshine.

supported by attractive tariff and government programs. Globally, solar PV prices are declining, making solar PV the least cost option for individual home systems in many remote locations. With dramatic cost reductions for solar panels and larger hybrid systems for remote communities, grid connected options are being considered by a number of developing countries.

Solar energy systems are particularly favored as an independent, accessible, and affordable source of electricity in rural areas, and in settings where central power generation and distribution is considered unreliable, e.g., where conditions are economically or politically unstable. Global PV capacity has increased by more than 40 percent a year since 2000. The International Energy Agency predicts that by 2050, PV will provide 11 percent of global electricity production, significantly reducing greenhouse gas (GHG) emissions and improving energy security and economic development.

China and India have the most developed PV industries in the developing world. India has ten companies manufacturing PV components for rural, remote, and industrial sectors; however, the technology is still only a small part of India's overall installed power generation capacity. In Brazil, PV technology is likewise becoming more widespread, where it is used primarily for telecommunications, rural electrification, water pumping, and public lighting in low-income communities.

Solar Thermal

Global solar thermal energy capacity also increased in 2012 to an estimated 282 gigawatts thermal [GW_{th}]. China and Europe are responsible for the majority of this capacity and account for 90 percent of the world market. Besides China, Japan and India have the largest solar thermal markets in Asia; Thailand follows close behind with new solar-waste heat hybrid system incentives. In South America, the Brazilian market has grown extensively, partly because of a program that requires solar thermal energy in low-income housing. In Africa, Egypt, Mozambique, Tunisia, Zimbabwe, and South Africa are the predominant users of solar thermal energy.

The International Energy Agency estimates that developing countries must double their energy capacity by 2020 to meet energy needs. Thus small-scale projects to improve access to solar energy are of considerable importance.

Acknowledging the "Dark" Side of Solar PV

Continued growth in the deployment of PV cells over the next two decades could lead to the consumption of significant shares of the current world supply of gallium, indium, selenium, and tellurium.

Additionally, the mining of these metals for PV cell production has indirect environmental impacts that should be considered during selection of project technologies.

From a GHG emissions perspective though, the life-cycle emissions from even the highest emitting solar PV production processes result in significantly less GHG lifecycle emissions per kWh of electricity than traditional fossil fuels such as coal-fired power.

PHOTOVOLTAICS

Inadequate access to electricity continues to be a major contributor to poverty among communities living in non-electrified areas.

Photovoltaic power is the direct production of electricity resulting from light hitting a solar cell and energizing electrons. Once electrons reach a certain energy level, they can drive current to power devices, including lights, batteries, communication systems, signaling systems, remote refrigeration, and pumps. **Silicon** is the leading material used in solar cell production because of its high efficiency. However, its high costs and limited supply to sustain long-term growth in the PV industry have led researchers to explore other options, mainly **thin film**. Thin film has a lower efficiency than silicon, but uses less material, lowering manufacturing costs.

Case Study: Ujala "Programme for Light", Pakistan

The Punjab provincial government is tackling the issue of growing power cuts by providing students in government schools in three districts with solar kits, consisting of a 30-watt solar PV cell, battery, and mobile phone charger. With 10 hours of charging from sunlight, the system can light a 40-watt bulb for 18 hours.

In January of 2013, 15,000 solar lamps were distributed to students, many of whom are not connected to the national grid and require lighting at night to complete school assignments.

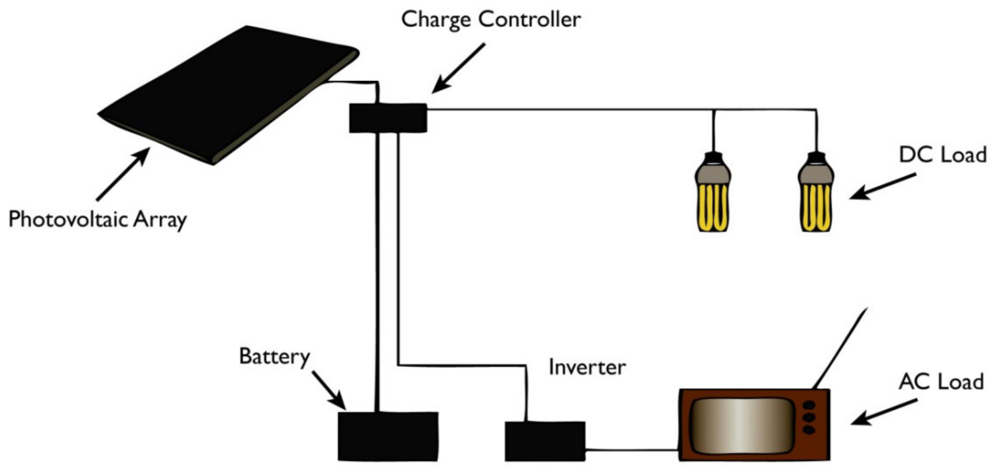
See http://www.trust.org/item/?map=solar-lamps-light-up-education-in-power-short-pakistan for additional information.

When multiple solar cells are integrated, they constitute a PV "panel" or "module", and when a group of modules are connected, the system is called a "PV array". (See the Practical Action Factsheet on Solar Photovoltaic Energy for descriptions of specific module and array types.)

PV modules for off grid applications generally require additional components, known as balance-of-system (BOS) components, which include a charge controller, battery, and possibly an inverter to convert DC to alternating current (AC). No fossil fuel is needed, and PV systems are generally considered environmentally benign and easy to maintain. PV systems in grid-connected applications are very common in developed countries and do not require batteries or charge controllers to operate.

Securing your Solar Power

Solar systems and batteries can be a target for theft in developing countries due to the high value of the technology. Proper installation with theft-proof hardware, as well as frequent surveillance and maintenance checks, are keys to securing your solar energy.



BOS Components of a typical off-grid PV system.

Source: Practical Action. http://practicalaction.org/solar-photovoltaic-energy

Pico PV Systems. Pico PV Systems combine lights (mostly LED) with charge controllers and efficient batteries that are powered by a small PV panel (generally less than 10 watts (W) rated output). Small essential needs can be provided with this type of system, such as lighting, phone charging, and radio use. The smallest of these systems cost between $10 to $50 USD, and can be expanded with additional kits and adapted for use with more energy-intensive appliances, such as small TVs.

Household PV. Since many developing countries (especially in the tropics) can harness solar energy year round, household level PV technology is being increasingly applied in rural areas, where grids are unrealistic. Like pico PV systems, these systems generally include PV modules, a charge controller, and at least one battery to store energy for use during non-sunny periods. These systems range from 10 to 200 W, which is sufficient to power household loads such as lights, radio, charging mobile phones, and possibly modest refrigeration (e.g. for vaccines). A major barrier to the uptake of PV technology is the high price of investment, but prices of solar panels have declined to around $1/W out of an average $4-$5/W total system cost.

Similar to household systems, **Institutional solar systems** power similar loads at community centers or groups of households, where electricity is accessible to the whole community. These systems are often appropriate in rural areas where connecting to a standard grid is not an option. Centrally located PV systems can also be used to charge portable batteries, which in turn can be used for electricity in rural households.

Micro-grid systems (micro-grids) provide a centralized power source for limited energy rural lighting, water pumping/treatment, and health care clinics. These systems are commonly utilized for the electrification of groups of collocated off-grid households and/or institutions. For example, more than 2.1 million of these systems have been deployed in Bangladesh, helping rural villages grow into centers of commerce.

While such systems can oftentimes lower PV costs through economies of scale, the economics and feasibility of centralized systems ultimately depend on the reliability of grid power, regulatory mechanisms, and the availability of battery banks (although a hybrid solar-diesel combination can be used without on-site battery storage).

The Times of India: Panasonic India launches solar lantern project

CHENNAI: Panasonic India launched its 100 thousand solar lantern project, a project to contribute 100,000 solar LED lights to people without electricity by 2018, the year which would mark the 100th anniversary of the company.

Panasonic aims to contribute 10,000 units of solar lights in three regions across Asia and Africa. As the first stage, 3000 solar lights were distributed in February 2013 in Myanmar. About 5,000 compact solar lights have been allotted to off-grid areas in India and 2,000 more will be given to a refugee camp in Africa, according to a statement from the company.

Source: Sushma, TNN.

http://articles.timesofindia.indiatimes.com/2013-03-08/chennai/37560642_1_solar-lights-panasonic-india-renewable-energy

Rural household and school lighting provide significant social and economic benefits in developing areas. Since children usually help with chores or attend school during the day, access to light at night allows them further opportunities to do their homework. It also permits adults to work longer, both on income-generating and educational activities. In addition to the economic potential night lighting holds, it also improves health and environmental prospects by mitigating pollution generated from stoves; oil and paraffin lamps; and candles.[2]

PV water pumping from wells can be used for village water supply and for providing water to livestock. Solar pumps must include a PV array which converts light into DC electricity, which in turn powers an electric motor to drive the pump. Types of solar pumps include submersibles, floating motor pump sets, and surface suction pump sets. Descriptions can be found in the Practical Action Factsheet for Solar (PV) Water Pumping. This guideline does not cover the use of solar pumps for large-scale irrigation.

Prior to implementing a project involving PV pumping, attention must be paid to ensure technical feasibility and environmental soundness. Particular attention must be paid to water quality and quantity as outlined in the USAID Sector Environmental Guideline on Water and Sanitation, which covers siting issues, required water testing, water table assessments, and the sustainability of hydrological conditions. Where new well(s) need to be drilled, environmental impacts can be significant (refer to the mitigation table below, specifically for land and water use). In examining solar pump cost-effectiveness, two important factors to consider are the quantity of water needed per day and the lift[3] required.

Health care. PV technology can light rural clinics and extend the use of medical facilities, including operating rooms during emergencies as well as powering diagnostic tools. Additionally, PV electricity can power communication and IT systems in remote locations. It can also power refrigeration for vaccine and blood storage, sonograms, ventilators, and microscopes.

SOLAR THERMAL ENERGY

Solar thermal energy uses different types of collectors to transform sunlight into heat for a variety of applications, from heating water to cooking meals. An advantage of solar thermal energy is that it can be

[2] See http://www.adb.org/news/videos/solar-lanterns-light-villages-india and http://live.wsj.com/video/solar-lanterns-bring-light-to-rural-india/DF984955-AFB1-4C0E-9C0C-02AA32A3A247.html#!DF984955-AFB1-4C0E-9C0C-02AA32A3A247

[3] Lift refers to the height that the water is raised by the pump.

manufactured with simple equipment and on an even smaller scale than PV technology, providing local economic benefit when community members are trained in building and maintaining these systems.

A common application of solar thermal technology is **solar water heating**, although household systems are mainly only found in wealthier areas in the developing world. They may be incorporated widely in urban areas through government incentive programs that reward households with solar hot water heating systems. Many of these systems have quick paybacks[4] when compared to standard electric or gas-fired water heaters (about two years payback for electric systems and more than six years payback for gas), and can be especially important in rural settings that depend on wood to heat water for households, institutions, and micro- and small enterprise uses. In many areas of the developing world, solar water heating systems are often extremely simple and built with inexpensive local labor/materials.

An Indirect Solar Food Dryer in Afghanistan

Photo credit: Robert Foster, Winrock International.

Solar thermal energy can also be used to control the drying of various crops and products, such as grain, fruit, coffee, and fish. **Solar drying** technologies consist of placing product in a drying box, and using the "stack effect" so that cool air and warm air circulate to remove moisture while the sun dries the product (alternatively, a fan may be used to provide circulation). Solar drying relieves environmental pressure by reducing the amount of fuelwood burned for crop drying while reducing spoilage and depletion of nutrients during the drying process.

Solar cooking is another application of thermal energy. The basic design of a solar oven is a box with a glass cover lined with insulation and a reflective surface to concentrate heat onto pots. Pots can be painted black to attract more heat. While these cookers are only effective during times of direct sunlight and require a longer cooking time than many conventional methods, they do not require wood, which puts less strain on the environment where wood is a major source of cooking fuel and allows women to concentrate on other activities besides collecting fuel. Some solar cookers, rather than being oven-like boxes, use a parabolic dish to concentrate sunlight onto a burner plate that can be used to fry and cook food quickly, so long as direct sunlight is available. There are many commercially produced solar cookers available, as well as a robust history of solar cooking using locally constructed cookers around the world.

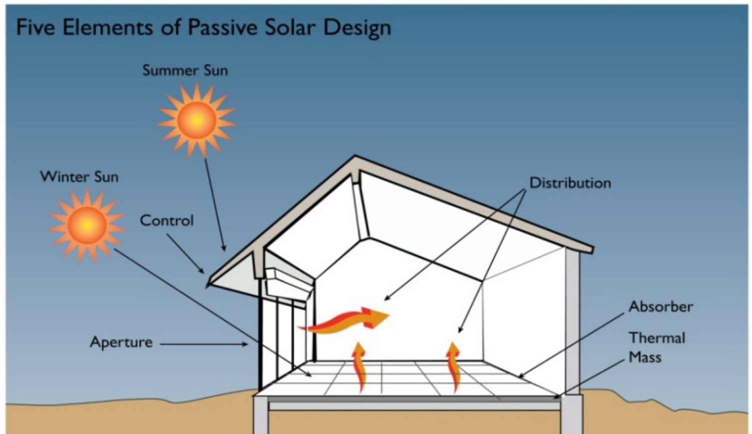
Solar water purification is a method for decontamination of drinking water. Using a transparent glass or plastic cover over a shallow tray of water with a black backing allows the sun to heat the water. The water then evaporates and condenses on the underside of the cover. The cover is tilted so the clean water can be drained into a separate collector. Another option is pasteurization, which heats water to 65 degrees Celsius (°C) for six minutes, killing bacteria and parasites harmful to humans. This type of

[4] Payback is the period of time required to recover the costs from an initial investment.

pasteurization is readily achievable using very basic materials, such as glass bottles laid on hot urban rooftops in sunny weather.

Solar thermal refrigeration uses a solar collector to provide heat to a cooling system of refrigerants in collector tubes. A thermal storage tank receives and stores the refrigerants, which then power the thermal air conditioning (AC) unit for refrigeration. A heat exchanger is used to circulate heat between hot and cold spaces.

Passive solar designs utilize the natural energy of the sun to improve thermal comfort in a structure without the use of mechanical devices. Design strategies can be used to both heat and cool buildings. Orientation, location, and landscaping changes have the potential to reduce a building's energy requirements by 20 percent. For example, facing windows towards the midday sun in cold climates can reduce the need for mechanical heating. If solar design is employed early on in the building process, heating and cooling costs can be substantially reduced with rapid payback periods for incorporating passive solar features in the initial building design.



Elements of Passive Solar Design

Source: http://www.wbdg.org/resources/psheating.php

ENVIRONMENTAL IMPACTS AND MITIGATION MEASURES

Compared with fossil fuel based energy, solar energy produces fewer air emissions. There are, however, potential environmental impacts associated with the construction, operation, and decommissioning of certain solar power systems, including pollution to nearby environments and GHG emissions.

The table below provides an overview of the principle environmental impacts associated with small-scale solar energy projects. For each potential environmental impact listed, recommended mitigation and monitoring measures are provided. For each mitigation and monitoring measure, the phase during which the recommended action should occur is marked per the following key: Planning & Design (P&D), Construction (C), Operation & Maintenance (O&M), and Decommissioning (DCM).

Note: The environmental impacts and corresponding mitigation and monitoring measures included are intended as guidance. While these lists are intended to be extensive, they are not meant to be comprehensive, and one should always assess impacts at the project-specific level to ensure appropriate treatment of issues.

Furthermore, the below table should not be used in lieu of a project-specific Environmental Mitigation and Monitoring Plan (EMMP). A template for such project-specific EMMPs is provided in ANNEX I of this document.

ENVIRONMENTAL IMPACT	MITIGATION MEASURES	MONITORING
Land Use Changes. Land use changes can affect ecosystem services in the area. Consideration should be given to minimize changes that will have the most negative impact on significant ecosystem services and sensitive habitat. For example, land and soil in the designated area can be affected by land clearing, construction, and disassembly of both thermal and PV systems (especially if a well needs to be drilled for a PV pumping system). These actions can negatively impact water supply and water quality as well as sensitive biological or cultural sites.For large enough ground-based systems, land changes can result in habitat loss and/or interfere with existing land uses. After construction, however, much of the land around the array will repopulate with local flora, though some mowing and maintenance will be required for operations. Typically, PV power plants require about 100 ft2/kW of land (assuming peak generation). Solar thermal systems are predominantly located on rooftops. In such cases, land changes are not a significant concern."	• Small-scale PV systems should be constructed on household or building roofs when possible. (C, P&D) • Refer to the USAID Sector Environmental Guideline for Construction for guidance on mitigation of environmental impacts associated with these aspects of solar energy projects.	• Refer to the USAID Sector Environmental Guideline for Construction for guidance on monitoring environmental impacts associated with these aspects of solar energy projects.
Pollutants. Liquid coolant changes required during operation of solar thermal systems create a risk for accidental water contamination. PV systems face low risks of accidental pollution, except in the case where a system fire could release pollutants into the environment. In these cases, the risk of pollutant emissions is consistent with similar risks from any electrical system. PV systems in developing countries typically rely on battery packs. Batteries contain toxic materials that must be disposed of as hazardous waste when battery life is over.	• Develop and assess waste management and disposal plans with vendors and end users at the concept and design stage. (P&D) • Ensure old PV batteries are separated from other solid wastes and disposed of with other hazardous waste materials, e.g., paints and toxic chemicals. The waste management plan should account for all such potentially hazardous wastes in full. (P&D, O&M, DCM)	• Evaluate implementation of waste management plans bi-annually. (O&M) • Test nearby water quality bi-annually to ensure no contamination from coolants. (O&M) • Ensure proper battery recycling facilities are available and provide oversight of the recycling process. (P&D, O&M, DCM)
Visual Impacts. Solar panels and large solar arrays may be considered aesthetically displeasing, especially in rural and culturally sensitive areas.	• Engage with community during planning to minimize adverse aesthetic and view impacts, with attention to siting and design. Provide for improved system integration with buildings. (P&D, C)	• Conduct stakeholder and community surveys prior to, and throughout, project implementation. Typically, bi-annual or quarterly consultations

ENVIRONMENTAL IMPACT	MITIGATION MEASURES	MONITORING
		are appropriate. (P&D, O&M)
Water Use. Drilling a well for solar water pumping can disrupt natural groundwater flow, supply, and quality. Alterations of the natural pressure gradient during drilling can also interrupt water production of nearby wells. Periodic cleaning of PV panels may be necessary in areas with limited rainfall, and requires non-trivial amounts of water. For utililty-scale PV, 26-30 gallons of water are needed per MWh.	• Cement seals can be used to separate and protect surrounding rock, soil, and groundwater. (C) • New wells should be a safe distance from already existing wells to avoid changes in pressure gradients that could affect existing wells. (P&D, C)	• Follow mitigation and Monitoring Guidance found in the USAID Sector Environmental Guidelines for Water and Sanitation. (P&D, C, O&M)
Indirect Impact. PV systems requiring mining of silica and various metals include 'energy metals' such as gallium, indium, selenium and tellurium. These impacts may not be apparent to end users, but should be addressed as part of lifecycle environmental assessments of PV projects. Also not apparent to end users is the manufacturing process of PV systems, which is energy-intensive. The amount of hazardous materials depends on the cell type, with mono crystalline cells containing the most dangerous materials. During regular processes, gases that are used such as silane and phosphine are not dangerous as air emissions, but are highly toxic in the case of accidents or leaks.	• When possible and cost efficient, vendor solicitations and awards should provide source/origin provisions that demonstrate due diligence in mining and processing of the metals and raw materials used in the manufacture of PV systems. (P&D) • Proper mitigation measures include procurement provisions requiring recycling used chemicals, taking appropriate precautions during manufacturing (wearing personal protective equipment, etc.), and proper project siting and design. (P&D, C, O&M) • To minimize environmental impacts related to production, thinner cell layers and safer and more efficient production materials should be explored. (P&D)	• Require source/origin self-certification. Apply spot auditing where feasible. (P&D, O&M) • Review occupational health and safety actions annually. (O&M) • Track number of on-site injuries and accidents. (O&M)
Security. High value technology like solar PV systems can be a major target for theft. Battery theft can have a particularly negative environmental impact, as thieves are known to dispose of battery fluid haphazardly.	• Proper installation and positioning (out of easy reach) of solar systems with theft-proof hardware, battery cages with mesh. and secure mounts. (P&D, C)	• Require timely/scheduled maintenance of solar systems to deter theft and maintain equipment. (O&M)

ENVIRONMENTAL IMPACT	MITIGATION MEASURES	MONITORING
	• For community systems (or at hospitals, schools, etc.), community involvement and/or hiring a guard to protect the equipment can be effective. (O&M) • Train solar panel operators and maintenance works on theft prevention measures and strategies. (O&M)	• Review theft prevention measures and strategies annually. (O&M)

WIND POWER

Wind power can offer a cost-competitive rural electrification option, particularly in remote areas with abundant wind resources.

Wind turbines in Sri Lanka. Photo credit: Fairway Holdings.

OVERVIEW

Wind energy projects can vary widely in scale and siting. Single, **small-scale wind turbines**[5] may be used for water pumping and irrigation, or to provide power for rural schools, hospitals, and individual households. Multiple turbines may also be utilized for community electrification; large commercial and institutional applications; or small island wind projects.

Unlike small-scale wind developments, **large-scale wind farms** for power generation may span hundreds of acres either on land or offshore. This guideline briefly discusses large-scale wind power, but the primary focus of this section is the potential beneficial and adverse environmental impacts resulting from the use of small- and medium-scale wind energy systems to meet energy demands in developing contexts.

TRENDS, ECONOMICS, AND CHALLENGES

Globally, wind power is a rapidly growing source of energy generation. Between 2007 and 2012, wind power generation grew at an annual rate of 25 percent. While much of this growth was driven by large-scale installations and investment in developed countries, ongoing investment in large, emerging markets (e.g. China and India) and new investments in an ever-expanding list of countries suggest a promising future for the industry. China installed 13 gigawatts (GW) of wind power in 2012. Over the same period, India added more than two GW of wind power.

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[5] For the purposes of this guideline, ***small-scale wind turbines*** are turbines generating up to 100 kilowatts (kW) of power, as defined by the U.S. National Renewable Energy Laboratory (NREL). NREL defines ***medium-scale wind*** as turbines generating between 100 kW and 1 MW of power.

In Latin America, Brazil, Mexico, Argentina, Chile, Uruguay, Costa Rica, and Nicaragua are among the countries that have invested in wind energy. In Africa, the growth has been less pronounced, though Tunisia, Ethiopia, and South Africa each installed at least 0.5 GW of wind power in the past year.

Battery Storage Units

The reliance on battery storage units in off-grid applications means that project design must account for the associated environmental considerations.

Lead-acid batteries, which are most frequently used in off-grid storage applications, come in two primary varieties: ***flooded*** and ***valve-regulated***. From an environmental planning perspective, these differ in that flooded lead-acid batteries release high volumes of hydrogen and oxygen gasses produced during normal operation. These gasses are potentially explosive, and if batteries are stored in a poorly ventilated area, pose significant risk to project implementers and beneficiaries!

By contrast, valve-regulated lead-acid batteries recombine the hydrogen and oxygen gasses produced during normal operation within the battery. While some gas is still released, it is nominal compared to flooded lead-acid batteries, and only modest ventilation is required.

More generally, lead-acid batteries contain a variety of potentially hazardous materials. Proper security and disposal of batteries is essential to minimize risk of harmful exposure.

Refer to the USAID Powering Health resources on Batteries and Battery Management and Theft Prevention for additional information on the use and management of batteries and battery storage units.

Small-scale wind energy has yet to see rapid growth, though that is starting to change. The increased prevalence of micro-grids and distributed energy resource (DER) systems (discussed in greater detail in the Distributed Energy Resource section of this guideline) has created infrastructure more supportive of small-wind technologies. Recent trends suggest that the market is favoring turbines producing at least 50 kW, as the financing is easier at that minimum size.

Overall, the cost of small-scale wind is becoming increasingly competitive compared to other small-scale energy generation systems, with recent estimates as low as $0.05 per kilowatt hour (kWh), though more conservative estimates tend to range from $0.15-$0.35/kWh.

As wind turbines require significant upfront capital investments and, for larger installations, complex siting and installation requirements, larger projects are generally more cost-effective than small-scale projects. Because of low operational costs after installation, the relative savings from bulk wind farm capital investment and installation can yield lower-cost electricity (e.g. $0.04-$0.16/kWh).

APPLICATIONS OF SMALL-WIND POWER TECHNOLOGIES

Household and institutional wind applications. Increasingly, small-scale wind turbines offer a competitive alternative to diesel and other traditional means of rural electrification both in cost and implementation. Projects can be sized to provide sufficient power for houses, schools, farms, and hospitals, with many generating fewer than 5kW of power.

In many cases, connection to a national grid can be cost-prohibitive for projects aiming to address the modest electricity needs of many rural areas throughout the developing world. Additionally, locating small turbines so that they connect directly to buildings, or to local village micro-grids, can offer greater assurance of electricity than an unreliable, centralized power source. Wind turbines for off-grid applications incorporate (typically battery) storage, controls, and power conditioning equipment (also known as **balance-of-system** components). While these systems are costly to implement, they can be provide uninterrupted power for hospitals, communications equipment, and other critical loads.

The variability of wind resources arising from daily fluctuations in wind speeds favors hybrid systems that include both photovoltaic (PV) solar technology as well as smaller wind turbines. Coupling wind turbines with PV offers the opportunity to harness power during cloudless, low wind weather and during darkness or overcast conditions.

Wind turbines in grid-connected applications are cheaper and simpler to implement, and can increase grid reliability and reduce the risks associated with management of battery storage units (see text box at left).

Wind-Powered Water Pumping. While mechanical wind-powered water pumping is a centuries-old technology, more advanced wind-powered water pumping technologies have been relatively slow to gain widespread popularity. Although newer wind-powered water pumping technologies would be well-suited to rural developing areas, limited familiarity with – and availability of – these technologies restricts their use. Wind-powered water pumping technologies are becoming more affordable and can provide enough water to satisfy the needs of small rural villages. As discussed above, hybrid systems involving both wind and PV systems can provide greater assurance. Refer to the technical factsheet developed by Practical Action for additional information on wind water pumps.

Community Wind Projects. Projects that share energy benefits among groups of people are referred to as community wind projects. Collective investment and ownership in, for instance, a 100 kW turbine, can yield energy benefits for a variety of end users. Successful community wind projects have been implemented in a variety of contexts, including schools, towns, farm cooperatives, and islands.

The text box "*Cabeólica, Cape Verde: Small-Island Wind"* below offers a closer look at an island wind farm project on Cape Verde.

Cabeólica, Cape Verde: Small-Island Wind

In 2009 the Government of Cape Verde developed *Cabeólica*, a public-private company charged with developing Cape Verde's wind potential.

As a state comprised of nine small islands, Cape Verde regularly receives moderate to high winds (up to 10 meters per second), and the cost of transporting diesel fuel to power generators is extremely expensive.

In 2010, *Cabeólica* raised $78 million in financing from the Africa Finance Corporation, Finnfund, InfraCo Ltd., the European Investment Bank, and the African Development Bank. With these funds, *Cabeólica* commissioned the development of four separate wind farms in 2011 and 2012, comprised of thirty 850 kW wind turbines for a total capacity of 25.5 MW. Through this investment, Cape Verde meets nearly 20% of its electricity needs with wind power, while reducing diesel usage by 22,000 tons.

The projects in Cape Verde are indicative of the potential viability of wind power options where wind resources are readily available, government and private sector communities are aligned, and other alternative energy options are either environmentally unfriendly or economically unattractive.

Source: Ashden Awards, 2013. http://www.ashden.org/blog/what-small-island-can-teach-rest-world-about-wind-power

ENVIRONMENTAL IMPACTS OF SMALL-SCALE WIND POWER

The table below provides an overview of the principle potential environmental impacts associated with small-scale wind power, as well as recommended mitigation and monitoring measures. For each mitigation and monitoring measure, the phase during which the recommended action should occur is marked per the following key: Planning & Design (P&D), Construction (C), Operation & Maintenance (O&M), and Decommissioning (DCM).

These environmental impacts, mitigation measures, and monitoring measures provided below are intended as guidance. While these lists are intended to be extensive, they are not meant to be comprehensive, and one should always determine potential impacts at the project level prior to implementation to ensure appropriate project design.

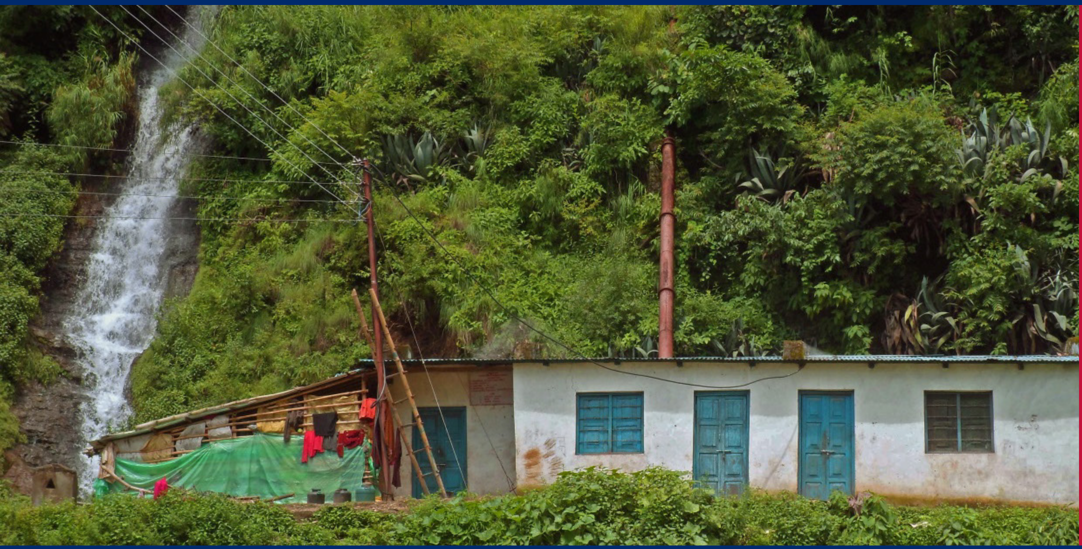
Furthermore, the below table should not be used in lieu of a project-specific Environmental Mitigation and Monitoring Plan (EMMP). A template for such project-specific EMMPs is provided in ANNEX I of this document.

ENVIRONMENTAL IMPACT	MITIGATION MEASURES	MONITORING MEASURES
Avian Risk and Biodiversity Risks. While small-scale wind turbines generally do not pose significant avian threat due to their low height and small rotor diameters, birds and bats may collide with operating turbines, or be injured during flight by air pressure fluctuations caused by the spinning blades. As with any construction project, land alteration land alteration may create competing land uses that have variable impacts on ecosystem services as well as on the habitats of sensitive flora and fauna..	• Conduct a predevelopment and/or an ESV assessment to ensure that biologically sensitive areas are avoided. (P&D) • Avoid projects in areas with endangered bird and/or bat species when possible. (P&D) • When project siting may affect endangered or threatened species, operation of wind turbines may be limited to prevent substantial impact (e.g. a study of bat behavior has shown they are more active during periods of lower wind speed). (O&M)	• Tracking instances of injury to avian or bat species. (P&D)
Land Disturbance. For smaller scale wind turbines, land disturbance is generally not a significant environmental impact. Typically, less than 1 acre of land per MW is permanently disturbed from wind turbine operations and for small-scale wind towers. This means that overall land use is minimal, but consideration should still be given to ensure that valuable ecosystem services and sensitive habitats are unharmed.	• Where applicable, use the site of the wind turbine installation for alternative uses such as agricultural production or grazing for livestock, to minimize disruption on utilized land. (P&D, O&M) • Conduct a predevelopment assessment and/or an ESV to ensure that construction avoids biologically sensitive areas as well as areas critical to providing valuable ecosystem services.	• Engage the community with regards to project siting, design, and management prior to project implementation. (P&D) • Interview community members prior to project implementation to ensure that land use is compatible with wind development. (P&D)

ENVIRONMENTAL IMPACT	MITIGATION MEASURES	MONITORING MEASURES
	(P&D) • Establish a protocol and budget for the removal of turbines at the end of useful life. (P&D, DCM)	
Noise and Visual Impacts. Wind turbines produce noise and can impact site aesthetics and viewsheds. These impacts are typically minimal for small-scale wind installations and not of a scale to adversely affect community health. Notwithstanding, community preferences must be planned for from project outset to ensure that the project is compatible with the needs of the local community.	• Involve community (and/or household) members during project siting and design, seeking input to ensure siting and selection of technology is in line with community needs and that adverse impacts on aesthetics and areas of cultural or historical value are avoided or minimized. (P&D) • During planning, assure the siting of the wind system minimizes noise impacts on the local community. (P&D)	• Conduct stakeholder and community surveys during concept preparation. (P&D) • Conduct periodic interviews with community members to gauge community satisfaction with the installation and efforts to minimize or avoid adverse impacts on aesthetics or on sensitive cultural or historic areas. (O&M) • Track community complaints about noise. (O&M)
Public Health. Standing water from spillage around wind-driven water pumps may become a health risk. As with any water system, overgrazing near the water supply can be a serious problem, especially in arid and semi-arid environments.	• Establish fee-based wind pump/water use committees during concept stage and train community members on proper maintenance of wind-powered water pump systems and how to identify and address equipment problems. (P&D, C, O&M) • Provide training and implement awareness campaigns to alert project beneficiaries to potential health risks. (O&M) • Conduct a predevelopment assessment and/or an ESV to ensure that construction and land use will avoid risks to water supply and quality. (P&D) • Ensure grazing activities at the site of the water pump are minimized or eliminated entirely. (P&D, O&M) • Utilize an automatic shut-off mechanism to avoid spillage around water pumps. (P&D, C, O&M)	• Establish water use committee to conduct weekly checks on equipment function and to maintain records on the number of community members trained, or reached via awareness campaigns. (P&D) (O&M) • Maintain monthly records of the number of water-borne illnesses. (O&M)

ENVIRONMENTAL IMPACT	MITIGATION MEASURES	MONITORING MEASURES
Water Use. Wind-powered water pumps address significant areas of need. However, they are only effective if the siting of wells and/or the selection of pumps takes into account the suitability of the water source, including sustainable yield and seasonal water quality.	• Refer to the *USAID Sector Environmental Guideline on Water and Sanitation* for best practices regarding sound design and management of water wells.	• Refer to the *USAID Sector Environmental Guideline on Water and Sanitation* for best practices regarding sound design and management of water wells.
Battery Use. Small-wind systems designed to operate in the absence of grid power often rely on battery packs. Batteries contain toxic materials that must be disposed of as hazardous waste when battery life is over. Additionally, some flooded lead-acid batteries, while less expensive, require storage in well-ventilated areas to reduce risk of build-up of potentially combustible hydrogen and oxygen gasses released during operation.	• Develop and assess waste management and disposal plans with vendors and end users at the concept and design stage. (P&D) • Ensure old batteries are separated from other solid wastes and disposed of with other hazardous waste materials, e.g., paints and toxic chemicals. The waste management plan should account for all such potentially hazardous waste in full. (P&D, O&M) • Select batteries based on storage location, considering factors such as ventilation and temperature. • Secure batteries such that they cannot be stolen to be sold for scrap metal or used for alternate purposes.	• Evaluate implementation of waste management plans bi-annually. (P&D, O&M) • Track incidences of stolen materials. (O&M) • Track the number of accidents resulting from battery use or exposure. (O&M)

SMALL HYDRO POWER



Small-hydro projects are implemented using various designs, with the design determined by site-specific conditions, such as flow rate, head, water level, and seasonal fluctuations in water availability.

This image of a micro-hydro operation located in Nepal shows the penstock feeding into the powerhouse, as a stream continues to flow alongside. Photo Credit: Winrock International.

OVERVIEW

Hydropower operates by converting the flow of water resources into electricity. Flowing water is **abstracted –** or taken – from the source water-body (usually through canals) and dropped through a **penstock** (usually a plastic or steel pipe) into the **powerhouse**, where the turbine and the generator (coupled to the turbine shaft) is rotated by the force of flowing water and generated power is transferred to the community via transmission lines. The mechanisms and structures that control the direction of flow of water abstraction are generally referred to as **headworks**. As water leaves the hydro system, it flows from the powerhouse through the **tailrace**, a channel below the dam, weir, or turbine. Ultimately, the amount of electricity that can be generated depends on how high the water drops and the volume of water flows through the turbine blades. This is as a function of:

- Speed at which a volume of water is flowing (**flow rate**) through the turbine;
- Height difference between the upstream water level elevation and the elevation of the water upon exiting the turbine minus head losses inside the penstock (**net head**); and
- Combined operating efficiency of the turbine and the generator.

This section provides an overview of small-scale hydro power generation best practices, environmental impacts, and mitigation strategies.

Small-scale hydro is defined here as a hydroelectric generation facility producing less than 10 megawatts (MW) of power.[6] Subsets of small-scale hydro (or *small-hydro*), often referred to as ***mini-*** and

[6] In some countries, such as India and China, small-scale hydro is defined as hydroelectric power generation up to 25 MW. Other countries, e.g., the U.S., consider small-scale to be up to 30 MW. This guideline uses a scale of 10 MW, adopted by the International Energy Agency (IEA).

micro-hydro, are also covered in this section. Mini-hydro is defined here as a hydroelectric facility generating between 100 kilowatts (kW) and one MW of power; micro-hydro is defined as generating less than 100 kW.

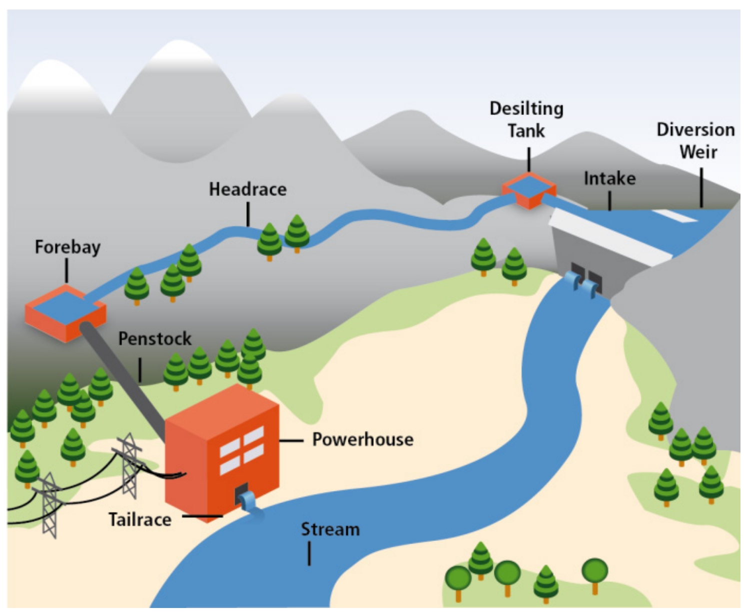
TRENDS AND ECONOMICS

Small-hydro has gained popularity in rural development because system design and implementation is often cost-competitive relative to off-grid power generation from traditional fossil-fuels, or to grid-connected power solutions in remote rural areas (see the Cost Consideration section of this guideline for a table comparing life-of-project costs of common renewable energy power generation projects). The technologies are viewed as no-carbon, with low- or no GHG emissions during operation. In addition, once installed, the power produced can provide a source of revenue for communities or, if connected to a grid, larger power suppliers.

Internationally, small-hydro is currently most prevalent in Asia. India has over 3500 MW of small-hydro power currently operational.[7] China has over 45,000 plants, for a total capacity greater than 50 GW. China also utilizes the full range of functional applications for small-hydro, with connection to centralized electric grids as well as use in smaller, isolated grids or off-grid applications. Most other Asian countries including Nepal, Sri Lanka, Bhutan, Indonesia, Afghanistan, Pakistan, and the Philippines also employ small-hydro for on-grid as well as rural electrification.

By contrast, in Latin America, medium- and large-scale hydro power is predominant. Overall, hydro power accounts for more than 60 percent of Latin America's electricity generation. Because of the significant regional hydropower supply, diversification of electrical generation in Latin America has trended toward wind, solar, and biomass rather than small-hydro.

Sub-Saharan Africa has the most unrealized potential for small-hydro development. Only an estimated 5 percent of hydro resource potential had been tapped as of 2006. However, countries including Rwanda, Kenya[8], Ethiopia, South Africa, Zambia, and Mozambique are increasingly investing in small hydro or micro hydro projects. Both integrated on-grid projects and off-grid rural electrification projects are gaining prominence. While opportunities are increasing, expansion has been hampered by poor regulatory regimes, fiscal mismanagement, inefficient operations, and limited incentives.



Each hydroelectric design offers advantages and disadvantages depending on the efficiency of utilization of the available water resource, the extent of impacts on the environment, and the cost of project implementation.

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[7] Per the previous footnote, this total includes some small-hydro plants that generate between 10 and 25 MW; however it should be noted that average project capacity is only 3.8 MW.

[8] Presently, over 50% of Kenya's energy supply is derived from hydropower.

TECHNOLOGY APPLICATIONS

RUN-OF-THE-RIVER VS. RESERVOIR

Most hydro projects fall into one of two categories: 1) ***Reservoir*** or 2) ***Run-of-the-River (RoR),*** though some variation does occur within these categories.

The vast majority of donor-assisted small-scale hydro projects are **RoR** systems, which function by diverting water from the river into a low gradient headrace canal to gain a desired head and dropped through a penstock (pipeline) to the turbine (typically located in a powerhouse) which powers the generator. With environmentally sound siting and design, RoR projects typically have minimal impacts on downstream river flow and carry the additional benefit of a lower upfront capital investment compared to reservoir hydro projects. Notwithstanding, potential impacts such as decreased flow rate, alterations to sediment loading, or soil erosion, among others, may still require project implementation of mitigation and monitoring measures to ensure no significant impacts. Additionally, where multiple RoR projects exist on the same river or water body, cumulative impacts may become significant, especially to water supply, biodiversity, and any sensitive fisheries, (see the text box below on *"Cascading Hydro"* and this guideline's section on *Cumulative Impacts*), requiring watershed-level planning and regulation.

RoR schemes do have technical limitations. Because they are dependent on natural flow rates, they are typically susceptible to seasonal flow variability, which can present a challenge in maintaining reliable electricity generation. Where feasible, integration of RoR hydro schemes into Distributed Energy Resource (DER) and grid systems can lessen vulnerability associated with flow variations. See the Distributed Energy Resource section for additional discussion of DER systems.

Some of the vulnerability of RoR schemes can also be mitigated through the addition of **weirs**. Weirs are relatively small, dam-like structures that regulate flow rates and water levels, thus improving the reliability of power generation, particularly during seasonal low-flow periods.

Case Study: Cascading Hydro in India

A single small-hydro plant in Uttarakhand, India draws water through a 4-km tunnel along the river. This site, by itself, reduces flow rates but may not cause major harm to the local ecosystem.

However, the same river also supports two other projects. One, called Kaliganga I, is a 4 MW RoR scheme. The other, Kaliganga II, is a 6 MW scheme. These two additional RoR projects use another 2.4 km of tunnels along the same river. Additionally, the projects are effectively adjacent, with the Kaliganga II desilting tank beginning from the tail-race of the Kaliganga I project.

The end result is that a stretch of the original river is completely dry, leaving native flora and fauna without the water resources needed for survival. It is essential when planning and siting potential projects to take proper stock of pre-existing activities and, to the extent possible, understand the cumulative effects of project implementation.

Reservoir systems involve the construction of dams to reduce flow variations. Reservoir hydro can regulate the flow rate and head of the hydro system by controlling upstream water levels, as well as the timing, level, and rate of water discharge to ensure reliable and constant power. However, ***even small-scale reservoir schemes have the potential for significant adverse environmental impacts***—reservoir hydro schemes are typically subject to a thorough Environmental Impact Assessment (EIA). Sound environmental design and management of these systems is essential to reduce risk and mitigate adverse impacts.

TURBINES

Hydro turbines also fall into two broad categories: impulse and reaction. Impulse turbines operate in air, and as water flows it hits the blades or runners of the turbine and rotates the turbine to generate electricity. **Impulse turbines are typically best suited for sites with higher head, but lower flow rates**.

This micro-hydropower turbine and generator brought electricity and excitement to a remote community in Brazil. 2006.

Photo Credit: Nazareno Natalino, Indalma Industria

Reaction turbines, on the other hand, are enclosed in a casing and fully submerged in water. The turbine's blades are angled such that changes in pressure resulting from water flowing through the casing are captured by the blades, causing the turbine blades to rotate. **Reaction turbines generally operate most effectively in areas with lower head and higher flow rates.**

There are multiple common classes of turbine within the two categories. Common impulse turbines include Pelton, Turgo (a variation on Pelton), and cross-flow. Reaction turbines include Propeller, Francis, and Kinetic. The U.S. Department of Energy (DOE) provides helpful definitions for these technologies, available at http://www1.eere.energy.gov/water/hydro_turbine_types.html.

FISH-FRIENDLY DESIGN FEATURES

Recent innovations in turbine design have focused on technologies that reduce environmental impacts, with a particular emphasis on **fish-friendly technologies**. The Alden turbine, for example, has a slower-moving corkscrew design that reduces fish mortality.

To protect the downstream migration of local fish species, **fish screens** are frequently installed at the mouth of the intake channel. These prevent the majority of fish from entering the intake channel, minimizing the risk of fish being trapped, injured, or killed by the turbine.

Fish Passes, Fish Ladders, or Fish Elevators are options to prevent the disruption of upstream fish migration. The construction of weirs with large drop offs – as can occur with broad-crested weirs and sharp-crested weirs – can block upstream migratory patterns, as can damming. Fish passes are small diverted channels that maintain the original water levels of the water body. Fish ladders are alternate routes, with a series of incremental "steps" at heights that do not inhibit migration. Fish elevators actually use a physical lift, one sufficiently filled, to carry fish over the barrier. Fish passes are more common on smaller-scale projects, while fish ladders and elevators are more frequently used on larger projects with high dams.

WEIRS

Relative to dams, weirs provide a lower-cost, lower-impact technology to increase upstream head and to measure and regulate downstream flow. Weirs temporarily block flow of water to create a small head and ensure that the desired flow is diverted into the headrace canal through the intake. By filtering water through a designated area (of specified shape), weirs allow for clear measurement of the volume of water passing through or above the structure. Additionally, weirs help ensure that sufficient water is channeled through the headrace canal into the penstock (for RoR schemes) during low-flow periods.

The selection of the appropriate weir depends on site-specific conditions, as different weir designs have different sets of benefits and drawbacks. The resource *River Weirs, Good Practice Guide* (2003) provides in-depth evaluation and discussion of different weir structures, their potential applications, and the associated environmental impacts (see the annotated bibliography for additional information).

ENVIRONMENTAL IMPACTS AND MITIGATION MEASURES

The table below provides an overview of the principle environmental impacts associated with RoR hydro projects. For each environmental impact listed, recommended mitigation and monitoring measures are provided. For each mitigation and monitoring measure, the phase during which the recommended action should occur is marked per the following key: Planning & Design (P&D), Construction (C), Operation & Maintenance (O&M), and Decommissioning (DCM).

The included environmental impacts, mitigation measures, and monitoring measures are intended as guidance. While these lists are intended to be extensive, they are not meant to be comprehensive, and one should always assess impacts at the project-specific level to ensure appropriate treatment of issues.

Furthermore, the below table should not be used in lieu of a project-specific Environmental Mitigation and Monitoring Plan (EMMP). A template for such project-specific EMMPs is provided in ANNEX I of this document.

RUN-OF-THE-RIVER

Depending on the ecosystem in which a RoR system is installed, many of the environmental impacts can be mitigated with a thorough site analysis during the project planning phase and subsequent incorporation of appropriate mitigation measures and life-of-project monitoring. RoR systems that involve the construction of large weirs can include some of the risks and considerations for reservoir hydro.

ENVIRONMENTAL IMPACT	MITIGATION MEASURES	MONITORING MEASURES
Local Hydrology. Small-scale RoR schemes have the potential to alter local hydrology, and therefore impact ecosystem services like water supply and quality in addition to biodiversity. Where water is diverted through a penstock, the main waterway is affected, at minimum, by reduced flow levels. Reduction in water flows can introduce temperature changes, affect sedimentation levels in the water, and disrupt migration patterns of native fish and other riverine fauna and	• Assess baseline water use demand and needs in the area through consultation with local water users. (P&D) • Conduct thorough baseline pre-assessments of site conditions, including historical flow rates, seasonal flow rate variations, water temperature, water resource needs, baseline sedimentation levels, and local flora and fauna most likely to be affected. ***Do so prior to any final determinations of site location and design***. Incorporate measures in design to mitigate impacts to ecological goods and	• Measure and maintain records of high-flow and low-flow rates, and seasonal flow variability. (P&D, O&M) • Reassess local hydrology annually. (O&M) • Biannually summarize the number of instances where thresholds for abstraction during high- or low-flow periods are violated. (O&M) • Monitor flood levels and the ability of the weir to withstand flooding and ability of protection walls to contain flood flow. (O&M)

ENVIRONMENTAL IMPACT	MITIGATION MEASURES	MONITORING MEASURES
flora. Additionally, weirs change upstream and downstream water levels and (potentially) flow rates. The change in water levels, if significant enough, can increase upstream flood potential, alter rates of downstream sedimentation, and affect terrestrial species and aquatic flora and fauna reliant on both upstream and downstream resources. Failure of weirs/dams can flood downstream communities.	services. (P&D) • Ensure projects maintain 10% to 15% of the dry season flow as "environmental flow" in the dewatered section of the river year-round as an accepted practice to minimize impact on aquatic flora and fauna. (P&D, O&M) • Adjust abstraction to account for seasonal flow rate variations so that 1) high flows are not reduced excessively from over-abstraction, and 2) the flow rate never becomes so low as to completely dry out, or substantially reduce, overall water level. (O&M) • Design projects **exceedance flow** at 90% for micro-hydro and 60-70% for small-hydro systems. **Exceedence flow** refers to the percentage of time the river flow is above the design flow. (P&D) • Build weirs to withstand maximum design flood levels, including potential climate change impacts. Flood protection walls need to be adequately designed and constructed to both protect structures at the headworks and confine all maximum expected flood flow within the river channel. (P&D, C) • Site weirs away from areas that pose flood risks to downstream and upstream communities. (P&D) • Carry out repairs immediately after flood season to avoid serious damage to weirs and other structures at the headworks such as intakes, gravel traps, and de-silting tanks. (O&M)	

ENVIRONMENTAL IMPACT	MITIGATION MEASURES	MONITORING MEASURES
Soil Erosion. Alteration to the local hydrology and flow rates as a result of the introduction of weirs and RoR systems can lead to increased erosion and degrade ecosystem services like soil retention by leading to increased erosion along river banks and at the tailrace.	• Evaluate soil suitability to support altered hydrology prior to project implementation. (P&D) • Minimize flow fluctuations to the extent possible; select project sites that have lesser seasonal variability when feasible. (P&D, O&M) • Plant native vegetation along shoreline where possible to stabilize river banks. (P&D, C, O&M) • Design the tailrace to minimize erosion at re-entry points. (P&D, C, O&M)	• Monitor river bank stability through regular visual inspections and, where helpful, periodic soil analyses; evaluate river bank following all major storms, floods, or otherwise significant disruptive events. (O&M)
Loss of Biodiversity and Alteration to Habitats.[9] Habitats and biodiversity may suffer adverse impacts as a direct result of alterations to local hydrology (principally along the diverted section of the waterway). A reduction in water flow and/or subsequent change in water temperature can create conditions unsuitable for local flora and fauna, in turn creating indirect ecological impacts. Similarly, changes in water quality and/or sedimentation levels have the potential to create unsuitable conditions for aquatic flora and fauna, which can in turn impact terrestrial species or local communities.	• Conduct a thorough pre-assessment of the site conditions, including seasonal flow rate valuations, water temperature, water resource needs, baseline sedimentation levels, and potentially affected local flora and fauna prior to any final determinations of site design and location. (P&D) • “Offset” foreseeable and unavoidable impacts on local flora and fauna by replanting vegetation or re-populating fish at designated unaffected locations. (O&M) • Pay special attention to assessing presence of endangered species in unique habitats. (P&D)	• Establish pre-project baseline for riverine fauna and flora. Select key indicator species for monitoring purposes. (P&D) • Conduct a high- and low-flow biotic census biannually. (O&M)
Impediment to Fish Migration. RoR schemes can directly affect migratory patterns of local fish species. Fish migrating downstream can find the reduced flow of the waterway insufficient to support their migration. Likewise, if fish travel through the powerhouse,	• Design system to provide minimum “ecological flow” required at all times to support aquatic life. • Install screens at intakes to protect fish during downstream migrations (P&D, C) • Install “fish ladders” or “fish passes”	• High- and low-flow baseline pre-assessment census of biota, followed by bi-annual census of biota upstream and downstream, including migratory fish species. (O&M)

[9] For particularly small projects – such as micro- and mini-hydro projects – the impacts on biodiversity and habitat may be very small. The potential impacts should still be evaluated, but the extent of the evaluation must be commensurate with the scope of risk. Ultimately, ESDM requires that the environmental risk potential be properly understood **prior to project implementation**.

ENVIRONMENTAL IMPACT	MITIGATION MEASURES	MONITORING MEASURES
they may be caught in the turbine, resulting in injury or death. Weirs can obstruct fish migration. And, as with downstream migration, depleted reaches of the waterway may prove impassable or unfavorable for upstream fish migration.	to allow fish to circumvent weirs and/or turbines, when fish passes are required by local EIA regulations and/or when affected species will most likely benefit (e.g. when salmonids use the waterbody for upstream migration). (P&D, C) • Where possible, utilize "fish-friendly" turbine technologies. (P&D, C)	
Increase in Area Human Activity. The introduction of weirs, penstocks, and powerhouses all require modest on-site construction and development. In turn, RoR hydro power creates an increased human footprint in the area associated with construction. New roads (or expansion of existing roads) may also be required to provide construction vehicle access. An increase in waste and unused construction materials may occur. In some cases, there may be a requirement for constructing new transmission lines.	• Wherever possible, site and construct weirs in already developed locations, limiting the impact of new infrastructure or expansion of existing roads. (P&D, C) • Conduct a predevelopment assessment and/or an ESV to ensure that road development occurs in areas that minimize impacts to valuable ecosystem services. (P&D) • Clear only the minimally required amount of vegetation to enable construction; replant removed vegetation in unaffected areas. Many host country governments have laws and regulations regarding replanting of vegetation which are usually tied to approval of environmental permits. (C, O&M) • Conduct awareness campaigns for local communities and individuals new to the area about sensitive ecosystems and species in the project area. (P&D, C, O&M) • Refer to the *USAID Sector Environmental Guidelines for Rural Roads* and the *USAID Sector Environmental Guideline for Construction* for additional review of environmental impacts and mitigation guidance.	• Periodically (e.g. bi-annually) note changes from the baseline community human population over the project implementation period. (C, O&M) • Maintain records on replanted vegetation throughout construction. (O&M) • Refer to the each of the *USAID Sector Environmental Guidelines for Rural Roads* and the *USAID Sector Environmental Guideline for Construction* for additional review of environmental impacts and mitigation guidance.

RESERVOIR HYDRO

As mentioned in the discussion of RoR vs. reservoir hydro projects, small-scale reservoir hydro projects are quite infrequent. Notwithstanding, the environmental and social impacts resulting from the creation of reservoirs – even for smaller-scale (i.e. <10 MW) projects – can be significant, including potential flooding, major alterations to habitats of local flora and fauna; soil erosion; changes to water sedimentation levels; creation of barriers to fish migration patterns; and introduction of new roads, transmission lines, increased human traffic, displacement of individuals or communities, housing resettlement, and loss of historical or culturally significant areas.

It is important to note that most bilateral and multilateral donors, and many countries' environmental assessment laws require an Environmental and Social Impact Assessment prior to implementation of even small-scale reservoir hydro projects.

This guideline does not provide an environmental impact, mitigation, and monitoring table for reservoir hydro projects as the potential impacts are extensive and the implementation of such projects is uncommon. Substantial research is available which discusses the array of impacts and best practice mitigation measures associated with reservoir hydro power, with selected references provided in the annotated bibliography.

TRANS-BOUNDARY WATER RELATIONS

Hydro projects – even small-hydro projects – have the potential to engage **trans-boundary** actors. In particular, there can be substantial complications in assigning responsibility for downstream impacts when those impacts occur across the border from the site of project implementation. As an example, Liberia has access to potentially significant hydropower resources from the Cavalla River. However, this river is shared with a neighboring country, Cote d'Ivoire, and utilization of those hydro resources will require bilateral cooperation, including established rules regarding beneficiaries and responsible parties for project impacts.

That said, historically water issues have not led to armed conflict. Through collaboration and direct engagement, water issues instead can often result in cooperative agreement rather than conflict. The United Nations Educational, Scientific and Cultural Organization's (UNESCO) International Hydrological Programme (IHP) and World Water Assessment Programme jointly developed the *From Potential Conflict to Cooperation Potential* (PCCP) programme, a resource devoted to supporting peaceful and equitable resolution to trans-boundary water relations.

Another excellent resource is Oregon State University's Water Conflict Management and Transformation Program's Institute for Water and Watersheds, which houses substantial data and research on historical trans-boundary water conflicts and resolutions, potential sites of future water issues, and tools for assessing potential risk.

GEOTHERMAL

Geothermal technology utilizes steam or hot water reservoirs in the earth to generate electricity, heat and cool buildings, and in various agricultural processing applications.

Geothermal steam is condensed and converted to fresh water for agricultural production in Eburru, Kenya. Photo credit Robert Foster, Winrock International.

OVERVIEW

Geothermal technology utilizes steam or hot water reservoirs in the earth to generate electricity, to heat and cool buildings, and for various agricultural processing applications. According to a 2010 report from the World Geothermal Congress, the total capacity of geothermal plants around the world is approximately 11,000 MW. The availability of cost-competitive geothermal energy, its potential for energy savings, and the prevention of GHG emissions make it an important and growing source of energy for development.

Geothermal resources are generally located at three distinct depth horizons – deep, shallow, and superficial. The **superficial geothermal resources** are either very close to the earth's surface or take advantage of the ground heat near the earth's surface (10 - 15.5 °C). Milder heat is particularly well-suited to direct heating purposes, such as heating buildings and greenhouses. Areas with the highest underground temperatures and the highest geothermal potential are typically located in regions with active or geologically 'young' volcanoes. These areas tend to be seismically active (i.e. prone to earthquakes). Given the capital investment required for geothermal plant construction, these areas may present significant risk to a power generation facility.

Applications of geothermal energy, at both large and small scales, fall into two general categories:

<u>Direct use:</u>

- Utilization of the heat for heating/cooling buildings, agriculture and aquaculture, greenhouses, and industrial plants.

- Heat pumps: Targeting the shallow ground temperature for heating and cooling of buildings.

Electricity production: Hot water and steam from reservoirs drive large power generators to produce electricity.

TRENDS

Geothermal resources offer significant potential for a broad-based generation of renewable energy. Capital costs have been a significant barrier to large-scale geothermal development; however, costs of geothermal electrical production have been cut by half since 1980 in some areas and there is great potential for small-scale geothermal applications for agriculture, recreation, commercial applications, and small-scale industries.

Small-scale geothermal projects well-suited to serve rural populations are defined in this guideline as less than 10 MW. While small-scale geothermal projects have the potential to fulfill energy demand in developing countries, the primary challenge is securing financing due to high cost per installed kW and low rate of return.

Recent Developing Country Geothermal Investments[10]: Recent growth in geothermal technologies in developing countries has been spurred largely by investment in larger-scale applications.

In Asia, Indonesia is a principal investor in geothermal technologies. The country added two 55 MW units at the Ulubelu station in 2012. Additionally, Indonesia announced plans both for a 1,000 MW geothermal energy investment program (with significant international backing) and a geothermal risk mitigation loan fund to serve as stimulus to developers. Looking to the future, Indonesia is targeting an increase in geothermal capacity from 1.3 GW at present to 12.6 GW of geothermal capacity by 2025. However, a 165 MW project on Bali was cancelled in the face of sustained local opposition based on environmental and religious concerns.[11]

In Latin America and the Caribbean, Nicaragua completed the second 36 MW phase of the San Jacinto-Tizate project in late 2012, having completed phase one a year earlier. The 72 MW project is expected to meet the equivalent of 17 percent of Nicaragua's electricity needs. El Salvador has long-term plans for an additional 90 MW of geothermal capacity and Chile has bids out for exploration in various areas. Several Caribbean islands have geothermal plans (including Nevis, Dominica, and the U.K. territory of Montserrat). Dominica is hoping to have an operational 10 – 15 MW plant by the end of 2015.2014.

Meanwhile, Kenya is Africa's largest producer of geothermal power, with a total installed capacity of more than 200 MW. Kenya is one of the largest investors in smaller-scale geothermal applications, recently commissioning the 2.5 MW Eburru wellhead plant in early 2012, and a 5 MW modular wellhead unit came online at a KenGen facility. In May 2013, Ormat Technologies announced commercial operation of a new 36 MW unit at the Olkaria III complex. The country is exploring public-private partnerships to take on the development of an additional 560 MW at Olkaria in four 140 MW increments.

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[10] REN 21 Renewables 2013 Global Status Report (GSR) Geothermal Heat and Power, p.34, available at: http://www.ren21.net/ren21activities/globalstatusreport.aspx.

[11] Wasti Atmodjo, "Bali to have adequate electricity supply: Minister," Jakarta Post, 4 September 2012.

Interest is growing elsewhere in Africa. For example, Rwanda recently committed funds to commence drilling to tap an estimated 700 MW of geothermal potential. Nevertheless, high exploratory costs associated with geothermal power are a significant barrier for African countries. The World Bank is addressing this issue and has established a Global Geothermal Development Plan to manage the risk of exploratory drilling in developing countries. Working with Iceland, the World Bank has also established a "Geothermal Compact" to support surface-exploration studies and technical assistance for countries in Africa's Rift Valley.

A $66 million USD (EUR 50 million) Geothermal Risk Mitigation Facility has been established for Eastern Africa (Ethiopia, Kenya, Rwanda, Tanzania, and Uganda) to support surface studies and exploration drilling. Eight projects have been short-listed following the first application round in late 2012. The Facility backing is from The African Union Commission, the German Ministry for Economic Cooperation and Development (BMZ), and the EU-Africa Infrastructure Trust Fund.

Case Study: Oserian Development Co. Ltd. (ODC) Geothermal Supplied Flower Farm – Naivasha, Kenya

ODC was established in 1969 as five-hectare vegetable farm, and in 1982, expanded to include cut flowers. Using a KenGen geothermal exploration well near Olkaria and Hells Gate, Kenya, ODC investigated geothermal use, studying the experience of Davao City, Philippines, where 60 percent of the country's cut flowers were being produced using a geothermal plant in a national park.

ODC contracted for a 1.8 MW binary plant in 2003. The plant was successful and ODC expanded their geothermal use. In June 2006, ODC purchased a new 2 MW geothermal turbine-generator set. It has been operating since November 2007 in parallel with the existing binary plant.

Current status. Today Oserian has greenhouses on 230 hectares and is exporting 400 million stems/year to Europe (30 percent of the European cut flower market) and is the largest geothermal greenhouse system in the world. The system is used for temperature regulation, rose health, and power generation for water pumping, lighting, humidity control, and computerization.

TECHNOLOGY APPLICATIONS

DIRECT HEAT USES

Direct use of geothermal heat is one of the oldest and most versatile methods of geothermal energy utilization. In modern direct use systems, a steady stream of hot water is accessed by drilling a well into a geothermal reservoir. A pump is generally used to deliver the heat and a disposal system disposes of the cooled water underground or on the surface. Since conversion does not take place, the process is highly efficient and can be used on both small and large scales.

The most common agricultural application of direct geothermal heating is in **greenhouses** to cultivate vegetables and flowers in off seasons and to create suitable growing climates. Operating costs, which can consume 35 percent of plant costs, can be significantly reduced by the use of geothermal energy in greenhouse heating.

Geothermal greenhouse applications can also be used in conjunction with **animal husbandry.** While animal husbandry is not a common application, animals can benefit greatly from the use of hot fluids to sanitize shelters and waste products. Heating a breeding installation takes only 50 percent of the energy required for a greenhouse of the same size, so cascade utilizations can be employed to maximize efficiency.

Aquaculture, controlling aquatic species' breeding, requires more significant temperature control than for land species, normally between 20 – 30 °C. Geothermal energy can be used to control the temperature of aquaculture facilities to produce larger/faster growing fish and to stimulate rapid algae production. For this sector to grow further there will need to be differentiation in species cultivated given that existing species have begun to level out market demand.

Oserian Development Company Flower Farm

Photo Credit: Geothermal Development Associates. Geothermal Power at Oserian Farms, Naivasha, Kenya,Second African Rift Geothermal Conferrence (ARGeo C2) Entebbe, 2008.

Food Drying. Geothermal energy can be used to heat the air needed to dehydrate food. Air is cycled through an air-water converter where it is heated to 40 – 100 °C. The heated air passes above trays or belts where the raw products are placed, facilitating the dehydration process. Normally, electric power is used to drive fans and pumps in geothermal food drying. This type of system can be used to dry onions, garlic, various fruit, and even grains, seaweed, and timber.

Geothermal heat is also viable for reliable **water purification and desalination** because the ground temperature at a certain depth remains constant throughout the year. With wells deeper than 100 meters, geothermal energy can be used to either heat the water directly or power reverse osmosis units to achieve purification.

Finally, a straightforward way to tap geothermal energy is to use **ground-source heat pumps** that can access the consistent 10 °C temperature just below the ground's surface. By recirculating either air or antifreeze liquid through underground pipes, the pumps can heat and cool buildings year-round.

ELECTRICITY PRODUCTION

Geothermal energy also can be converted to electricity with the use of **dry steam power plants, binary cycle plants, and flash steam power plants**. Small geothermal plants are typically binary or flash (or a combination of both), and wellhead generators (see below) are also becoming a viable option as demand for small-scale geothermal plants increases.

Each approach uses the same fundamental process: pull hot water and steam from an underground source, use it for energy, and return the used warm water back to the heat source. Details on the functionalities and differences between these plants can be found at the Union of Concerned Scientists website for geothermal energy.

Wellhead Power Generation units can be useful options for small-scale applications in remote locations because they are portable and reusable, and capital investment costs are modest. They can be used with wells that generate up to 15 MW, and due to the modular design of most wellheads, they can operate outside the reach of larger plants.

An example of such a wellhead is the **Eburru Wellhead Geothermal Pilot Power Plant** in Kenya. It was commissioned by U.S.-based Geothermal Development Associates in 2009 and is located at the Eburru geothermal field in Kenya (adjacent to the Ol Doinyo Eburru Volcano). It uses a 2.5 MW steam turbine generator set with auxiliary systems and controls.

Enhanced Geothermal Systems (EGS) is a new technology developed to capture heat in dry rock formations located 4 to 10 km below the surface. The environmental impacts of these systems, while potentially significant, are not examined under this guideline as they are still in the stage of limited testing and commercialization. However, significant progress with the technology is described in the *REN 21: Renewables 2013 Global Status Report.*

ENVIRONMENTAL IMPACTS

Geothermal energy has the potential to provide a broad-based, continual power supply with minimal impacts on the environment. However, as with most infrastructure developments, there are important environmental impacts that should be understood. Often geothermal resources are located in remote and ecologically sensitive areas, which may adversely affect vulnerable species and/or habitats. Nevertheless, compared to fossil fuel generation facilities, GHG emissions (e.g. carbon dioxide and methane) from geothermal plants are low. See Fridleifsson (2001) for a detailed discussion of GHG emission reductions from geothermal plants.

The table below provides an overview of the principle environmental impacts associated with geothermal projects. For each environmental impact listed, recommended mitigation and monitoring measures are provided. For each mitigation and monitoring measure, the phase during which the recommended action should occur is marked per the following key: Planning & Design (P&D), Construction (C), Operation & Maintenance (O&M), and Decommissioning (DCM).

The included environmental impacts, mitigation measures, and monitoring measures are intended as guidance. While these lists are intended to be extensive, they are not meant to be comprehensive, and impacts should be assessed at the project-specific level to ensure appropriate treatment of issues.

Furthermore, the below table should not be used in lieu of a project-specific Environmental Mitigation and Monitoring Plan (EMMP). A template for such project-specific EMMPs is provided in ANNEX I of this document.

ENVIRONMENTAL IMPACT	MITIGATION MEASURES	MONITORING MEASURES
Air Quality. Emissions of GHGs (carbon dioxide, methane), hydrogen sulfide, ammonia, , and trace amounts of other gases which can pollute the air and adversely affect human health. The main pollutant is hydrogen sulfide because of its odor.	• Use closed-loop systems that prevent gaseous emissions or emissions-capturing technologies. (P&D, C) • Use Personal Protective Equipment (PPE) during any drilling activities. (C, O&M)	• Conduct routine (e.g. monthly) analyses of outdoor and indoor air quality and investigation of human respiratory health impacts, including smell proxies by community members and facility workers. (C, O&M) • Take periodic measurements of lifecycle GHG emissions during production and processing of geothermal system components, transportation, and the end use of the fuel. (C, O&M)
Land Use. Depending on the size of the system, geothermal energy may use extensive tracts of land. The resource reservoir, amount of	• Incorporate predevelopment assessments in solicitations and awards and conduct them prior to implementation to ensure that	• Ensure sensitive area mitigation is incorporated though annual/biannual site visits. (P&D, C, O&M, DCM)

ENVIRONMENTAL IMPACT	MITIGATION MEASURES	MONITORING MEASURES
power capacity, energy conversion system, cooling system, arrangement of wells and piping systems, and the substation and auxiliary building footprints ultimately inform the scale of the project. Land in the designated area can be significantly affected by land clearing, construction, and disassembly of systems that have reached the end of their design lives. If a well needs to be drilled to tap geothermal resources there is a significant associated footprint. As geothermal resources are often located in remote and sensitive ecological areas, land changes can adversely impact ecosystem services -- such as water supply, culturally valuable land uses, cultural heritage, aesthetics -- as well as sensitive species and/or habitats.. • <u>Drilling Impacts:</u> Modifies surface morphology and potentially damages local plants and wildlife. Blowouts may pollute surface waters. • <u>Pipeline infrastructure</u>: Potentially impacts local plants and wildlife, soil, water bodies, wetlands, and visual aesthetics (viewsheds).	biologically and culturally sensitive areas are avoided. (P&D) • Establish and follow a protocol for replanting vegetation or repopulating affected species in areas affected by introduction of geothermal facilities. (C, O&M, DCM, P&D) • Experts should conduct predevelopment assessments to minimize erosion. (P&D, C)"Experts should conduct predevelopment assessements and/or an ESV to ensure that land use will minimize impacts to valuable ecosystem services. (P&D) • Project managers should consider habitat loss, rainfall and drainage interference when constructing geothermal systems, especially where biodiversity or threatened or endangered species may be affected. (P&D)	• Monitor and evaluate soil conditions annually during the life of the project. (P&D, C, O&M, DCM)
Noise. Noise is generated during steam extraction, vent discharge, and power generation from large fans, the steam ejector, and the turbines.	• During planning, ensure that the siting of the geothermal system minimizes noise impacts on local communities. (P&D) • If necessary, use mufflers and other soundproofing means to mitigate effects. (P&D, O&M)	• Conduct stakeholder and community surveys during concept preparation and mock-up noise tests. (P&D, O&M) • Conduct bi-annual stakeholder and community surveys to evaluate satisfaction with the project, including noise impacts. (O&M) • Track community complaints about noise. (O&M)

ENVIRONMENTAL IMPACT	MITIGATION MEASURES	MONITORING MEASURES
Water Resources. The temperature of discharge water may induce ecological phase shifts in receiving water bodies affecting water supply and quality.; if shallow groundwater is located above geothermal reservoirs, pressure drops in the reservoir could create cold down flow which can deplete fresh groundwater. Dissolved mineral liquid streams that result from well drilling can pollute surface and groundwater.	• Treat discharge of spent geothermal fluids containing boron, fluoride, or arsenic prior to discharge. (O&M) • Cool discharge water in ponds or tanks prior to release. (O&M) • Re-inject the geothermal wastewater into the source. (O&M) • Use well casings to create a barrier between the inside of the well and adjacent land. (P&D, C)	• Monitor the water table height, the availability of surface water, and its seasonal variability and quality on a periodic (e.g. biannual) basis. (P&D, O&M) • Monitor wells visually during drilling and operation for early detection and management of leaks. (C, O&M)
Health and Safety. Heat associated with geothermal sites and heat and power generation can pose threats to facility workers, farmers, rural populations, and children. Standard plant construction and O&M hazards must also be addressed. Vandalism and theft of equipment may occur.	• Design, train, and enforce safety protocols for plant construction, operation, and maintenance. (P&D, O&M) • Use wire fencing to protect equipment from theft/vandalism and to prevent community member facility injuries. For less-sensitive geothermal applications consider natural fencing. (C) • Ensure the use of appropriate PPE gloves, boots, and hard hats for employees and on-site visitors. (C, O&M)	• Conduct pre- and post-training testing of employees in safety protocols for geothermal operations (P&D, C, O&M). • Maintain systematic monthly inspection logs tracking use of PPE and on-site accidents. (C, O&M)

BIOENERGY

When produced responsibly, biomass can provide energy that decreases carbon emissions by displacing fossil fuels. However, in many cases, natural forest is cleared in unsustainable ways to provide for bioenergy fuel crops and leaves a site that cannot be regenerated.

Three women collect fuelwood. Photo Credit: Michael Benanav, Global Alliance for Clean Cookstoves.

OVERVIEW

Bioenergy, or biomass-based energy, is energy derived from living or previously living organisms. As a readily accessible and low-cost option, biomass accounts for about one third of all energy used in developing countries, with over two billion people globally relying on biomass fuel (primarily derived from wood and plant materials) for cooking and heating. In many developing countries, bioenergy use meets 80 – 90 percent of energy needs in rural areas.

Frequently, the unsustainable use of bioenergy contributes to substantial environmental degradation and resource scarcity, resulting in significant adverse social and economic impacts. While sound, sustainable strategies of bioenergy use can promote rural economic development, mitigate the impacts of climate change, and provide access to modern energy, poor strategies with short-term returns can impact valuable ecosystem services by creating biodiversity loss, deforestation, and additional pressures on water resources.

This section offers guidance on the environmentally sustainable implementation of small-scale bioenergy projects. Discussion of the impacts associated with larger bioenergy applications, such as steam or gas turbines using biomass, are not explicitly discussed, though some of the associated environmental risks overlap with those covered.

DID YOU KNOW…

A major impediment to widespread success of sweet sorghum production for bio-ethanol is the short "shelf life" of post-harvest yields.

As a relatively drought-resistant crop, sweet sorghum could potentially thrive in many parts of the world (particularly Sub-Saharan Africa), but the limitations on reliable infrastructure such as roads and transportation, post-harvest storage, and refining currently temper its prospects.

TRENDS

As populations increase, the number of people reliant on bioenergy has likewise grown—a trend that is expected to continue. The International Energy Agency (IEA) predicts that 100 million more people will use traditional biomass fuels in 2030 than today. In many cases, even when electricity is present (mainly in urban areas) solid fuels such as charcoal are still used for cost and cultural reasons.

Despite the fact that number of traditional fuel users is expected to increase, modern bioenergy technologies have been used in developing countries for decades, with continuous technological advances.

DID YOU KNOW…

1 to 2 cows, 5 to 8 pigs, or 4 adult humans are needed to supply a single-household biogas digester with enough feedstock to produce cooking energy for one day.

SOLID BIOMASS TRENDS

Solid biomass is the fourth largest source of energy in the world, trailing only oil, coal, and natural gas, and accounting for 10 percent of the global energy supply. Both traditional and modern biomass energy are predominantly used for heating. Modern biomass usage accounts for 3 to 4 percent of global energy demand, while traditional biomass usage contributes 6 to 7 percent.

DID YOU KNOW…

Charcoal production is a $10 billion industry in Sub-Saharan Africa alone and causes significant environmental destruction to forests felled to meet spiraling demand.

Regional surpluses and shortages of biomass feedstock have fostered the development of significant trade in solid (and liquid) biomass fuel; in 2012, around 8.2 million tons of pellets were traded internationally. Other internationally traded biofuel feedstock includes fuelwood, charcoal, briquettes, and agricultural residues.

Progress has been made in modernizing rural heating and cooking technologies, as well as providing education to rural populations on modern cooking and energy solutions. The number of developing countries transitioning away from traditional cookstoves and fuels is growing, but 76 percent of people in Sub-Saharan Africa still rely on traditional biomass technologies. These numbers are significantly lower in Asia and Latin America.

India's "National Cookstove Program" launched in 2012, with a goal of preventing 17 percent of premature deaths and disabilities related to traditional biomass emissions. In 2013 in Bangladesh, the World Bank initiated a program to provide rural homes with one million clean cookstoves and 20,000 biogas units, building off of Bangladesh's already strong commitment to biogas, with more than 30,000 such units in the country. In Latin America, both Mexico and Peru have large, ongoing programs to distribute clean cookstoves, which aim to provide one million units each. Several countries in Central America and the Caribbean, including Guatemala, Honduras, and Nicaragua, utilize carbon markets to support cookstove projects.

BIOGAS TRENDS

Biogas digesters were introduced extensively to developing countries in the 1970s and 1980s when high energy prices spurred alternative energy research. Biogas dispersion slowed in the late 1980s when its application was found more useful in industrial and urban waste treatment, but since 2000, the number of plants increased significantly again.

Biogas production has been the most successful in Asia, specifically China and India, where government campaigns popularized the technology. China has 27 million biogas digesters, and India has 4 million. These are primarily small rural bioreactors fed by animal manure. Nepal and Vietnam have had considerable success with household biogas with around 300,000 units installed each in last 25 years with 95 percent still operational. Facility age, maintenance, and ongoing investment have proven to be significant factors in digester success. While many digesters have been installed in Asia, around half are no longer functional.

In Africa, the Africa Biogas Partnership Programme (ABPP) has helped replicate Asian results. The ABPP is a partnership between the Hivos organization and the Netherlands Development Organization to support national biogas programs in Ethiopia, Senegal, Kenya, Tanzania, Uganda, and Burkina Faso. The program aims to use its approximately $42 million in funding to construct 70,000 biogas digesters. The Kenya National Domestic Biogas Programme is making use of the potential for 200,000 biogas plants in Kenya which could provide energy to one million people. The start-up phase aims to construct 12,000 biogas plants by 2014; 3,400 were constructed through 2010.

Biogas development is expected to accelerate, but it is hampered by factors such as the lack of access to building materials; the absence of institutions to promote and provide technical training and outreach; too little water; climates that are too cold or too dry; insufficient quantities of animal waste; high construction and operation and maintenance costs; low skilled labor availability; and government disinterest.

LIQUID BIOFUEL TRENDS

Current biofuel production and investment suffer from ongoing tensions associated with the ability to effectively implement projects without adversely impacting GHG emissions, directly competing with local food production and prices, or limiting beneficial returns to investors and stakeholders at the expense of the smallholder farmers supporting feedstock cultivation. Smallholder farms generally support a single family with a mixture of cash crops and subsistence farming. Notwithstanding, biofuel generation efforts are prevalent globally, ranging from palm oil, sugar cane, and jatropha in Asia; sorghum and cassava in Sub-Saharan Africa; and sugar cane and soybean oil in Latin America.

Overall, liquid biofuels account for roughly 3.4 percent of global road transport fuels—the largest percentage from any renewable energy source—but the growth of liquid biofuels in transportation has had mixed results. From 2007 to 2012, ethanol grew by 11 percent and biodiesel by 17 percent, but biodiesel production grew at a much slower rate than in the past, and ethanol production has declined since 2010.

SOURCES AND USES OF BIOMASS

Biomass sources can be broadly categorized into 1) agriculture and forestry residues (including by-products of food, fiber, and wood processing), 2) purpose-grown energy crops, and 3) organic waste. Bioenergy may be produced by burning solid biomass to produce heat or electricity or could also take the form of liquid or gaseous fuels used in stoves, engines, generators, and other equipment for cooking, lighting, heat, power, or transportation. Each particular source of biomass is more or less suited for different conversion processes and end uses. Biogas and liquid biofuels are explained in more detail in this section.

BIOGAS

Biogas is a gaseous product of the decomposition of organic matter without oxygen (a process known as anaerobic digestion). It is comprised of 50 to 80 percent methane and 20 to 50 percent carbon dioxide. Organic waste streams are the most common source of biogas used for energy and include livestock manure, human waste, food waste, and mill effluents, among others. Animal manure, due to its high moisture content, is efficiently converted to biogas, with cattle dung especially useful because cud-chewing animals have methane-producing bacteria in their stomachs. Human waste can also be used, but is more efficient when it is combined with agricultural substrate as the combination increases biogas yields. In Europe, cultivated energy crops are gaining popularity as biogas yields (particularly from grain crops) prove similar to those from animal waste. Potential energy crops for biogas in developing countries, such as rice straw and rice straw hulls, offer lower biogas yields.

Biogas technologies are considered a potential solution for both waste treatment and clean energy generation. The biogas production process also generates solids which can be used as an organic fertilizer, among other uses. The biogas itself can be used as energy for cooking, heating and cooling, and lighting. This guideline covers the production of biogas at various small-scale levels, from household biogas production from livestock or composting toilets, to farm and community level production from livestock, and also at the level of small municipal solid and liquid waste management.

LIQUID BIOFUELS

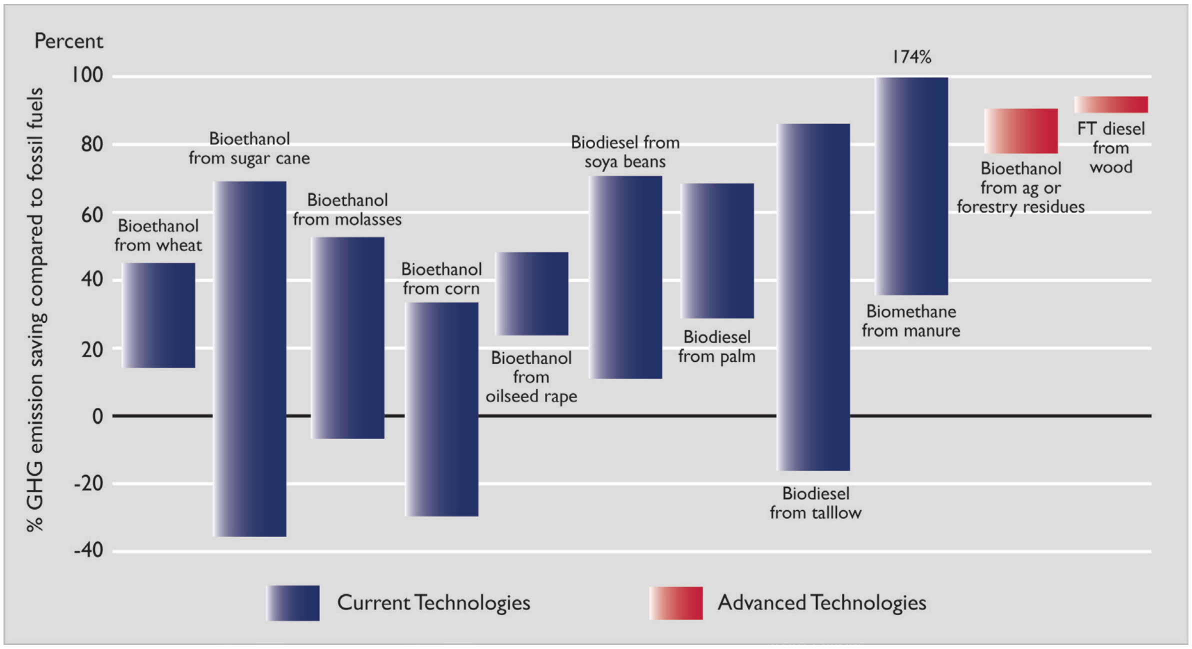
Liquid biofuels consist of **bio-ethanol** and **bio-diesel,** which can be used as alternatives to traditional gasoline and diesel, respectively. Bio-ethanol is typically produced through the fermentation of bio-wastes high in sugar or starch content, with the most common sources being sugar cane and corn. Bio-diesel is produced from oils found in plants, vegetables, or seeds (e.g. cassava, rapeseed, and palm oil), used in cooking oils, or even from animal fats.

Biofuels have gained popularity because of their potential to replace petroleum fuels, and the corresponding GHG, energy security, and air quality implications. Biofuels can be used for transportation, heat, and power. They may be considered for use in vehicles, machinery and modified diesel generator sets.

Biogas plant success in Rwanda

While larger-scale biogas plants are rare in the developing world, a promising example is in Rwanda, where five jails use bio-digesters to fuel more than half of the kitchens' energy.

The environmental and socio-economic benefits of biofuels have recently been called into question as recognition of the fact that the net impacts of biofuels across the lifecycle of their production and use may not provide a net positive benefit. A net increase or decrease of GHGs from biofuels compared to fossil fuels depends on various factors, such as the source of the biofuel, the land used for crop production, agricultural methodology, harvesting technologies utilized, and the refinement process. The following chart illustrates this variability, with bioethanol production from corn and sugar cane and biodiesel production from tallow serving as examples of biofuel generation with the potential to result in ***more*** GHGs than fossil fuels.



Source: data from IEA, 2011; graphic ©FAO, 2013.

Liquid biofuel projects range from large-scale investments to procure land and produce crops from which the biofuels can be generated to small-scale outgrower schemes. Examples of large-scale biofuel developments include much of the sugar cane-based ethanol production in Brazil, corn-based ethanol in the United States, and palm oil plantations in Malaysia and Indonesia. By contrast, outgrower schemes typically engage smallholder farmers directly and have often been cited as "pro-poor" projects relative to larger-scale biofuel projects stemming from the relatively increased share of benefits received by the farmers through land rents and crop revenues. Much of the current production of jatropha (discussed below in the text box *"Jatropha: the Risks of Next-Generation Bio-Fuels"*), for example, occurs through such outgrower schemes in Ghana, Tanzania, and Mozambique, among other countries.

PRODUCTION PROCESSES AND TECHNOLOGIES

Biomass energy is considered to be "modernized" when it is produced and converted into clean, convenient forms such as gases, liquids, or electricity (versus heat for cooking or warmth). A few bioenergy production processes and technologies are described below.

Biogas from Palm Oil Mill Effluent (POME) in Malaysia

In 2011, the palm oil industry accounted for the highest percentage of oil and fats production in the world. Malaysia is the leading producer and exporter of palm oil at 46% of world exports and 37% of world production in 2011. Poor handling of the wastewater produced from milling activities, known as Palm Oil Mill Effluent (POME), results in significant emissions of methane, contributing to GHG emissions and also causes pollution in the watercourses in which it is discharged. However, POME has a high organic content which makes it suitable for use in anaerobic digestion.

In 2011 alone, Malaysia produced an estimated 57 million tons of POME, which, if converted to biogas through anaerobic digestion, could power 700,000 households or offset the use of biomass and diesel during the palm oil production process. As of September 2012, 36 biogas recovery projects were under way in the palm oil industry in Malaysia (as registered with the country's Clean Development Mechanism program under the Kyoto protocol).

JATROPHA: The Risks of Next-Generation Bio-Fuels

Bio-diesel generation schemes based upon the jatropha curcas plant – a plant originally from Central America, though it thrives in both tropical and sub-tropical settings – saw a sweep of heavy investment during the mid-2000s. This investment was fueled by the understanding that 1) jatropha seeds contain a pure natural bio-diesel, which can operate in diesel engines straight from the plant, (with inexpensive treatment needed to remove elements harmful to the engines over the long-term); 2) the jatropha tree can grow on marginal lands and thus would not compete for scarce arable land; and 3) jatropha, as a toxic plant, provides potential sustainability benefits as a non-food crop.

However, little of the private and government investment in jatropha to date has yielded commercial success thus far. The financial crisis in 2008 saw many investors flee from speculative ventures such as production of bio-diesel from jatropha. Additionally, while true that jatropha grows on marginal lands, crop yields on such lands have proven much lower than in more suitable conditions, somewhat negating the notion that jatropha production can succeed without competing for scarce arable land.

As with many next-generation bio-fuels, the long-term potential for jatropha likely hinges upon the efficacy of current research developing improved seed varieties to produce more reliable, and plentiful, yields. As a non-food crop, jatropha is traditionally used as a natural fence, or for soaps, fertilizers, and medicines. It is only recently that such research and efforts to improve agricultural yield have been invested into jatropha. At this stage it is too early to tell whether jatropha will have commercial success, or whether it will prove most effective in isolated trials such as those in Mozambique and Tanzania.

GASIFICATION

Solid biomass can be converted to gas through high temperature (thermochemical) processes and either burned directly for cooking or heat supply, or used in secondary conversion devices like combustion engines to produce electricity. The gasifier device essentially burns the biomass with only enough air to convert the mass into a gaseous fuel, but without sufficient air for complete combustion. The "producer" gas that results has only 10 to 15 percent the heating value of natural gas, but requires significantly less biomass fuel to create the same amount of energy as direct burning. If gasifiers are closely coupled to gas burners, producer gas can be used in direct heating applications. Producer gas has been used extensively in household cooking, but requires gas storage, piping systems, and burners. In Shandong Province, China, producer gas generators have been installed to convert corn stalks into cooking gas to supply homes. Only half as much corn stalk is needed when it is used to produce gas rather that burning it directly as biomass. Producer gas can also be used to fuel diesel (compression-ignition) or gasoline (spark-ignition) engines to provide electricity for pumping, milling, lighting, communications, refrigeration, and other uses.

ANAEROBIC DIGESTION

Organic matter, such as livestock feces, slaughterhouse remains, effluents from agro-processing facilities, and crop residues, can be converted into biogas through anaerobic digestion, which converts the matter (usually in liquid form) to methane and carbon dioxide using bacteria. The biogas can then be burned directly for cooking or heating, or used in secondary conversion devices to produce electricity. Effective generation of electricity requires piping and biogas burners at cooking points, a spark or compression engine, and filters to remove water vapor and sulfur dioxide in the biogas.

In the agricultural setting of developing countries, small-scale anaerobic digesters usually use a semi-batch process where a fixed amount of manure and water are fed into the digester daily, as opposed to a continuous process where feedstock is added constantly. There is space in the digester for gas storage, and liquid sludge exits the digester into a storage tank and can be applied directly to fields as fertilizer. Additionally, this sludge can be de-watered in areas of water scarcity or high water demand, such as animal farms, to yield extra water that is then used to dilute fresh dung for additional biogas production

More details about the different types of anaerobic digesters can be found in "Design of Small Scale Anaerobic Digesters for Application in Rural Developing Countries" (Rowse, Laurel, 2011).

Anaerobic digestion can be employed at various production levels, from a single household to a farm/community level, and even to municipal waste management. It is important to consider the differing environmental impacts of projects at each of these levels.

Household Production. At the household level, biogas is mainly used for cooking and heating and the leftover slurry is used as fertlizer. Houses with biogas systems have significantly fewer emissions than households without systems, even when biogas systems have leakages. A report by Rajendran et al. shows that a three cubic meter, family-size biogas plant in India fueled by four cows had a global warming mitigation potential of 9.7 tons of carbon dioxide equivalent per year. While biogas systems still emit carbon dioxide and methane (which is exacerbated by leakages), burning methane through biogas use rather than allowing it to escape into the environment with poor manure management reduces the potential of the GHGs released.

Municipal Waste Management. Municipal solid waste (MSW) and wastewater (or waste water sludge) are wastes collected from domestic, commercial, and industrial sources (mainly in urban areas) that can be converted to fuel through several channels, including anaerobic digestion. Waste pretreatment might be necessary to separate organic waste from inorganic waste, to reduce the size of waste items, or to convert the MSW into slurry for use in certain digesters. ***The amount of energy input needed for pretreatment should be considered in project design***. Using anaerobic digestion for MSW management at a large scale is typically not feasible due to the need to sort waste during pretreatment. However, when possible this process can significantly reduce negative environmental effects associated with the biodegradation of organic waste in landfills and incineration, as well as from avoiding the use of conventional fertilizer by using bio-slurry. Gasification can also be used to convert MSW to fuel, and involves the partial combustion of MSW at a high temperature in a controlled environment.

Incineration of MSW requires controlled burning to oxidize almost all of the organic matter in the waste into steam to produce energy. It reduces the volume of the waste by around 90 percent and the weight by around 70 percent. The investment and operation cost of incinerators can be a limiting factor in developing countries. Additionally, incineration generally leads to more negative environmental impacts than anaerobic digestion. The resulting incinerator ash (about 10 percent of original waste) is often dumped in landfills, and incinerators with uncontrolled heat in areas of weak policy enforcement can create significant air pollution. In developed areas where this technology is most prevalent, scrubbers and filters can be used to reduce pollution and ash.

The production of biogas from municipal waste requires the collection and transportation of waste to a central location, and potentially secondary transport to a biogas plant. The environmental impacts of transportation and fuel consumption depend greatly on project variables, but should nevertheless be considered when planning small-scale municipal waste projects. See the *USAID Sector Environmental Guideline on Solid Waste* for more information on solid waste management.

Small-Scale Farm Biogas Production. Small-scale farms can benefit from biogas production through improved manure management practices, enhanced environmental outlook, and reduced need for the purchase or collection of energy (e.g. propane gas and firewood). As discussed previously, farmers additionally benefit since the sludge produced from the anaerobic digestion process can be used as an organic fertilizer, which decreases fertilizer costs. The *USAID Sector Environmental Guideline on Agriculture* provides additional information on the environmental impacts associated with fertilizer use in agriculture.

Effective operation of biogas systems on small-scale farms requires sufficient access to animal manure to allow for daily collection to serve as feedstock. While collection of manure can prove difficult, especially when livestock is not kept in a single location, the Global Alliance for Clean Cookstoves (GACC) estimates that 155 million households and commercial farms do in fact have sufficient access to animal manure. Biogas project may support improved manure management practices, while the termination of these projects may reverse the manure management gains, especially if practitioners return to poor manure management practices. *The USAID Sector Environmental Guideline on Livestock* provides additional information on the environmental impacts of cattle/manure management.

Another feedstock option for small-scale farms is the cultivation of energy crops, which can be combined with manure for co-digestion. When biogas projects include the cultivation of energy crops, the environmental considerations associated with land use, water use and resources, and GHG emissions (among others) associated with cultivation and harvesting must be considered. Additionally, government subsidies or other program incentives may be necessary for small-scale farmers to invest in biogas technology, as the start-up capital costs can be too high for most farmers in rural areas.

Community-Level Production. Community-level biogas plants can help address a community's common needs, including sanitation, energy security, pollution control, and employment generation. In India, the Sulabh organization has built 200 biogas plants that receive excreta from public toilets, producing one cubic foot of biogas per person, per day.

The case study below on the Cows to Kilowatts Initiative in Ibadan, Nigeria, provides an example of the potential environmental benefits resulting from effective biogas projects.

Community Level Biogas Production: Cows to Kilowatts Initiative Ibadan, Nigeria

In developing countries, abattoirs (slaughterhouses) are a significant source of water pollution and GHGs because of weak, absent, or poorly enforced regulations. In addition to generating methane and carbon dioxide from anaerobic degradation, slaughterhouse waste can also carry diseases that can seriously affect human health.

In Ibadan, Nigeria, a 3000 m^3 fixed film reactor was developed to convert abattoir waste from slaughterhouses into clean household cooking gas. Additionally, the biogas by-products can be used by farmers as organic fertilizer and the biogas can be sold for added profit.

This project, dubbed "Cows to Kilowatts", produces 1,800 m^3 of biogas daily and generates 1 MW of electricity for use by low-income communities. Cooking gas is provided to 5,400 homes.

Since biogas plant technology is not slaughterhouse-specific, significant potential exists for this type of project to be replicated and scaled up around the world.

For additional details, see http://www.wipo.int/wipo_magazine/en/2008/02/article_0002.html.

COOKSTOVES

Clean cookstoves are a particularly important technology for reducing biomass consumption in developing countries. Nearly half of the world's population burns biomass (e.g. wood, dung, and coal) to cook food and warm their homes in open fires or simple cookstoves. Inhaling acrid smoke and fine particulates from traditional cookstoves contributes to almost two million deaths per year worldwide, primarily women and children. Millions more have lung and heart disease or suffer burns or disfigurement from open flames and boiling water.

Artisanal energy efficient cookstoves. Source: Winrock International.

Beyond health impacts, the use of traditional cookstoves also has significant indirect environmental and social impacts. The collection of wood for charcoal production and fuel for cooking is a major contributor to the significant deforestation, loss of watershed, and desertification occurring in some developing countries. In Togo, the Democratic Republic of Congo, Cambodia, Guatemala, Madagascar, Tanzania and many other countries, the loss of forest canopy as a result of charcoal production has had devastating effects on biodiversity. In addition, emissions from simple cookstoves, including methane, carbon monoxide, nitrous oxides, and black carbon substantially contribute to global climate change.

Local manufacturing and sale of energy-efficient cookstoves, which can reduce biomass energy consumption by nearly 40 percent, has grown across Africa since their introduction in the 1980s. Often manufactured by artisans, these cookstoves typically require relatively nominal transportation and production costs, allowing their retail price to remain affordable for the intended beneficiaries. Designs range from small portable ceramic bowls to large installations with permanently fitted chimneys. The durability of these cookstoves varies from one year for the simplest versions to more than ten years for permanent cookstoves. The price varies correspondingly, from around $1 USD to more than $90 USD, depending on the design.

The GACC is attempting to address the health and environmental impacts associated with inefficient and traditional cookstoves by financing the purchasing of clean cookstoves and stove technologies, and developing international standards and rigorous testing protocols for cookstoves. Their ten-year goal is to foster the adoption of clean cookstoves and fuels in 100 million households. The specific cookstove technologies they support, and more information about their organization, can be found on their website.

Biogas has the potential to replace solid biomass in household traditional cookstoves that use charcoal or wood as fuel with significant resulting environmental consequences and health impacts, especially for women. The GACC focuses mainly on strategies to make the combustion of solid biomass more efficient, but there is renewed interest in biogas stoves and potential for their incorporation into the GACC's strategy. Biogas stoves use the aforementioned digester technology to convert animal and human waste into usable methane gas at the household level which can then be burned for simple cooking. However, while the environmental benefits are clear, any projects targeting this transition must account for the significant cultural base of cookstoves in many developing countries.

ENVIRONMENTAL ISSUES AND MITIGATION MEASURES

Modern bioenergy has the potential to meet the energy needs of many communities in a more environmentally and socially beneficial way than the traditional use of biomass-based energy or fossil fuels. Small-scale energy development projects to modernize biomass use in rural areas have become essential tools to improve energy services while reducing the likelihood of socio-economic concerns stemming from resources scarcities.

However, there has been increasing awareness in recent years of the potential negative impacts that bioenergy may have. Deforestation and land use changes have been connected with rising demand for bioenergy. Competition for land, water, and crop resources may also negatively affect food security and water availability. Use of biomass-based energy may also directly impact livelihoods through impacts on indoor air quality and security of supply. For example, rural women, traditionally responsible for gathering fuel wood, cooking, and collecting water in many areas, are particularly vulnerable to biomass resource scarcities. As wood and other biomass resources diminish, women must venture further and further to collect fuel wood and biomass, in turn losing time spent on other productive activities such as starting small enterprises that could bring money into the household. Furthermore, with longer distances to travel to collect fuel, women may be exposed to gender-based violence, especially in conflict areas. At a refugee camp in Eastern Chad, the majority of confirmed rapes have occurred while women were collecting firewood for fuel.

The particular positive and negative impacts of a bioenergy project are specific to local context where the project occurs. Addressing these local conditions is critical to the success of a bioenergy project. Consequently, it is of upmost importance for environmental impacts to be considered at the site and technology selection stages.

The environmental impacts of a particular energy project may relate to the agricultural or forestry activities that produce the biomass; transportation between the source of the feedstock to each point until its end use; the site clearance and construction activities for the project, access roads, and transmission lines; the operation and maintenance of the energy generation technology; and the end use of the energy. For the purpose of these guidelines, most of these stages are covered in other guidance documents in this series. The following table lists some potential environmental impacts and illustrative mitigation and monitoring measures for bioenergy projects at the site of energy generation and end use.

The table below provides an overview of the principle environmental impacts associated with bioenergy projects. For each environmental impact listed, recommended mitigation and monitoring measures are provided. For each mitigation and monitoring measure, the phase during which the recommended action should occur is marked per the following key: Planning & Design (P&D), Construction (C), Operation & Maintenance (O&M), and Decommissioning (DCM).

The included environmental impacts, mitigation measures, and monitoring measures are intended as guidance. While these lists are intended to be extensive, they are not meant to be comprehensive, and one should always assess impacts at the project-specific level to ensure appropriate treatment of issues.

Furthermore, the below table should not be used in lieu of a project-specific Environmental Mitigation and Monitoring Plan (EMMP). A template for such project-specific EMMPs is provided in ANNEX I of this document.

DESCRIPTION OF ENVIRONMENTAL IMPACT	MITIGATION MEASURE	MONITORING
ALL (BIOMASS, BIOGAS, BIOFUEL)		
Impacts from Construction, Introduction of Transmission Lines, and Development or Rehabilitation of Roads to support Bioenergy Projects. Bioenergy projects may require the installation of new technologies, construction of new buildings (or modifications to existing ones), introduction of new roads (or rehabilitation of existing ones), and/or the installation of new transmission lines. Such infrastructure development can result in adverse impacts on land use, impacts on land use and ecosystem services, such as soil retention, water supply and quality, aesthetics, and air quality, among others. It can also affect human health and safety.	• Refer to the USAID Sector Environmental Guideline for Construction and the USAID Sector Environmental Guideline for Rural Roads for guidance on mitigation of environmental impacts associated with these aspects of bioenergy projects. • Conduct a predevelopment assessment and/or an ESV to ensure that transmission lines or road development minimizes impacts on valuable ecosystem services. (P&D)	• Refer to the USAID Sector Environmental Guideline for Construction and the USAID Sector Environmental Guideline for Rural Roads for guidance on monitoring environmental impacts associated with these aspects of bioenergy projects.
Impacts from Agricultural Practices and/or Installation of Wells/Boreholes/Irrigation. Many sources of bioenergy rely on agricultural production or livestock to generate the feedstock necessary for energy production. Agricultural practices (from pre- to post-harvest), if mismanaged, have the potential for significant adverse environmental impacts, many of which are impacts on valuable ecosystem services. Soil retention and quality can be greatly impacted if nutrients are not managed sustainably (particularly as a result of overharvesting biomass feedstock, which can impact naturally balanced nutrient cycles) The use of agrochemicals can pose a risk to human health and safety and/or threaten area flora, fauna, and soil and water quality; and the introduction of new irrigation systems can draw unsustainability from area water sources or facilitate run-off of agrochemicals into area surface water bodies.	• Refer to the USAID Sector Environmental Guideline for Agriculture for guidance on mitigation of environmental impacts associated with agricultural production and/or irrigation for bioenergy projects. • Refer to the USAID Sector Environmental Guideline for Livestock for guidance on mitigation of environmental impacts associated with livestock management of bioenergy projects.	• Refer to the USAID Sector Environmental Guideline for Agriculture for guidance on monitoring environmental impacts associated with agricultural production and/or irrigation for bioenergy projects. • Refer to the USAID Sector Environmental Guideline for Livestock for guidance on monitoring environmental impacts associated with livestock management of bioenergy projects.

DESCRIPTION OF ENVIRONMENTAL IMPACT	MITIGATION MEASURE	MONITORING
Sustainability of Resources. Effective bioenergy projects must operate within the resource constraints of the project area; bioenergy production can threaten valuable ecosystem goods and services, especially local agricultural production and water supplies. Such changes could cultivate resentment among the affected community.	• Conduct a predevelopment assessment and/or an ESV to assess potential impacts to valuable ecosystem services. Attention should be paid to the area resources including, but not limited to, cultivable land, available water resources, water resource needs and uses in the area, land needs and uses in the area, competing food/bioenergy crops grown locally, prospective bioenergy crops, and feedstock storage options. (P&D) • Avoid siting projects in areas such that competing agricultural projects extend or relocate into ecologically sensitive, or carbon rich, areas. (P&D, O&M)	• Monitor area food availability and price – particularly of subsistence crops – to ensure relative stability upon introduction of the bioenergy project. (P&D, O&M) • Monitor the water table, availability of surface water, and its seasonality and quality. (O&M) • Monitor emergence or increases in need from competing uses. (O&M)
Land Use Changes. Producing bioenergy crops has the potential to create land use changes, both direct and indirect. With poor management, energy crops can impact a number of valuable ecosystem services. For example, they can contribute to deforestation and associated losses in biodiversity, water retention, and climate stability. By displacing farmland, they could also lead to the loss of soil retention and food supplies.	• Require under Implementing Partner (IP) awards that baseline assessments guarantee that no biomass fuel crops will be grown on land suitable for food crops. (P&D) • Plant bioenergy crops on brownfields, abandoned mining land, or other lower-quality areas to re-vegetate barren land, reclaim waterlogged or salinated soils, stabilize erosion-prone areas, provide habitat, and increase biodiversity. (P&D, C) • Conduct a predevelopment assessment and/or ESV to ensure that land use changes minimize impacts on valuable ecosystem services. (P&D)	• Conduct an independent site visit during design and annually thereafter to confirm that no land that could support food crops, degrade wetlands or natural habitats is utilized. (P&D, O&M)

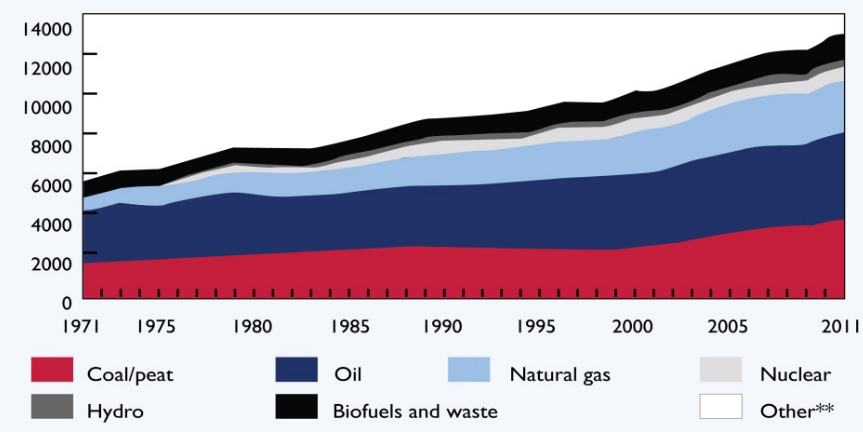
DESCRIPTION OF ENVIRONMENTAL IMPACT	MITIGATION MEASURE	MONITORING
Use of Water Resources at Point of Energy Production. Significant amounts of water may be used at the point of energy production. If not planned properly this can unsustainably reduce area water resources, threaten local flora and fauna, and threaten community wellbeing.	• Conduct a predevelopment assessment of water uses and water needs for the local community and local flora and fauna. (P&D) • Develop a water management plan, in coordination with the local community, during project conception and design. (P&D)	• Monitor the water table, availability of surface water, and its seasonality and quality. (O&M) • Monitor emergence or increases in need from competing uses. (O&M)
Chemical inputs and runoff. The processing and production of materials needed for bioenergy feedstock production and maintenance can emit pollutants into the atmosphere that impact both local and global air quality and climate stability.	• Recycle used chemicals when safe and appropriate; take precautions during manufacturing to minimize use, or waste, of hazardous materials as able; and ensure proper project siting and design ***prior to*** implementation. (P&D, C, O&M) • Develop and assess waste management and disposal plans with vendors and end users at the concept and design stage. (P&D)	• Conduct routine (e.g. biannual) analyses of soil, surface water, and groundwater. (O&M)
Waste Management. If managed improperly, the energy production process for bioenergy can result in a wide range of potentially harmful waste, including ash from biomass gasification and residual sludge from anaerobic digestion.	• Develop and assess waste management and disposal plans with vendors and end users at the concept and design stage. (P&D)	• Conduct a routine (e.g. quarterly) review of efficacy of the waste management plan to ensure waste is reaching designated disposal sites and all appropriate handling precautions are being followed. (O&M)
GHG Emissions. Land-use changes resulting from converting agricultural land for bioenergy production can result in net positive changes to overall GHG emissions that impact local and global climate stability and air quality.	• Evaluate the site suitability of proposed crop production site prior to project implementation. (P&D) • Avoid outdoor and indoor pollution from waste combustion and pollution from bioenergy cycle. (P&D, C, O&M) • Conduct a predevelopment	• Conduct analyses of outdoor and indoor air quality and investigate human respiratory health impacts regularly. (O&M) • Collect measurements of lifecycle GHG emissions during production and processing of bioenergy feedstock, transportation, and the end use of the fuel. (C, O&M)

DESCRIPTION OF ENVIRONMENTAL IMPACT	MITIGATION MEASURE	MONITORING
	assessment and/or ESV to ensure that land use changes minimize impacts to valuable ecosystem services. (P&D)	
BIOMASS		
Carbon Balances and Deforestation. When produced responsibly, biomass can provide energy that decreases carbon emissions by displacing fossil fuels. However, in many cases, natural forest is cleared in unsustainable ways to provide for bioenergy fuel crops, which leaves a site that cannot be regenerated. Such deforestation impacts many associated ecosystem services such as soil and water retention, climate stability, and cultural significance. In many developing countries, after biomass is collected it is inefficiently converted to heat energy for cooking (mainly by traditional cookstoves), producing damaging emissions like black carbon and methane which contribute significantly to global warming. Furthermore, the loss of forest canopy due to wood collection and charcoal production can have a devastating effect on local wildlife wildlife, decreasing local biodiversity.	• Conduct a prevelopment assessment and/or ESV to ensure that land-use changes minimize impacts to valuable ecosystem services provided by local forests. (P&D) • Use agriculture waste products of bioenergy crops as feedstock instead of natural forest. (P&D, C) • Use efficient stoves that can maximize the efficiency of solid biomass feedstock so that less fuel is needed. (P&D, O&M) • Utilize biogas and biofuel technology when possible to avoid the use of solid biomass as fuel. (P&D, O&M) • The United Nation's *Reducing Emissions from Deforestation and Forest Degradation (REDD+)* effort addresses the high rate of biomass-related carbon emissions through industry incentives to offset carbon emissions by sequestering carbon through reforestation and forest management. It offers incentives for developing countries to reduce emissions and includes roles for conservation and sustainable management of forests and forest carbon stocks. See the USAID Sector Environmental Guideline on Forestry and	• Analyze full fuel-cycle carbon emissions, both above and below ground for the entire biomass supply system. (O&M) • Measure annual harvest of wood resources. (O&M) • See the USAID Sector Environmental Guideline on Forestry and the USAID Sector Environmental Guideline on Agriculture for additional information. (P&D)

DESCRIPTION OF ENVIRONMENTAL IMPACT	MITIGATION MEASURE	MONITORING
	the USAID Sector Environmental Guideline on Agriculture for additional information. (P&D)	
GHG Emissions. The amount of emissions produced by clean cookstove technology is highly dependent on the efficiency of the cookstove in use.	• Use high-energy efficiency stoves to minimize emissions; advanced-fan stoves that improve the efficiency of biomass burning reduce the net warming impact by 60%. Gasifier stoves reduced net warming by 40%. (O&M) • Harvest solid biomass sustainably, for up to a 95% reduction in overall warming. (O&M)	• Analyses of outdoor and indoor air quality and investigation of human respiratory health impacts should be taken regularly. (O&M) • Collect measurements of lifecycle GHG emissions during the lifecycle of the fuel. (C, O&M)
Human Health. While clean cookstoves can reduce indoor air pollution that results in adverse human health impacts, they do not completely eliminate adverse emissions. Human health impacts depend highly on the efficiency of the cookstove in use.	• Use high energy efficiency stoves to minimize emissions and ensure cooking in well ventilated locations. (P&D, O&M)	• Conduct regular analyses of outdoor and indoor air quality and investigate human respiratory health impacts. (O&M)
BIOGAS		
GHG Emissions. When poorly managed, animal manure can be a major source of air and water pollution through nutrient leaching. The natural biodegradation of organic matter under anaerobic conditions releases 590-800 million tons of methane into the atmosphere annually. The animal production industry is responsible for 18% of overall GHG emissions. While biogas production is typically recommended to offset the environmental impacts of cattle production, biogas digesters can also cause environmental problems such as leaks from faulty digesters or intentional methane venting to avoid pressure build-up.	• Use proper planning and surveillance to mitigate the adverse effects of these problems on climate change. (P&D, O&M) • Use high-quality biodigesters to avoid methane gas leakages from gas collection chambers and pipings. Recycle water by separating solids from slurry.	• Collect measurements of lifecycle GHG emissions during the lifecycle of the fuel. (C, O&M)

DESCRIPTION OF ENVIRONMENTAL IMPACT	MITIGATION MEASURE	MONITORING
Pollution/Human Health. Biogas digesters themselves also face risks of leaking organic waste and incompletely sterilized slurry during digestion, leading to water and land pollution.	• Since effluents from digesters are often used in fertilizers, precautions are needed when human and hog feces are used as feedstock, as certain feces-borne parasites and pathogens can be dangerous for crop cultivation and human ingestion. (O&M)	• Regularly investigate human health impacts of biogas digesters. (O&M)
BIOFUEL		
"Anti-Poor" Development. Poorly planned biofuel generation schemes can undermine development efforts by limiting project beneficiaries to wealthy foreign investors or well-positioned local stakeholders.	• Design schemes to ensure project revenues are shared by project investors and smallholder farmers producing and managing feedstock crops. (P&D) • Provide ongoing training opportunities to smallholder farmers ranging from agricultural best practices and improved farming techniques to management, production, and distribution skills to promote long-term host country-operated bio-energy development opportunities. (O&M)	• Conduct community surveys to ensure smallholders a pre-determined share of project revenue. (O&M) • Track the number of individuals trained. (O&M) • Track changes in the number of host country-, or host region-, operated developments from project onset to close-out. (O&M)
Competition for Water Resources. The refining process for biofuels can be extremely water intensive, with water use rates potentially as high as 5 liters of water per liter of fuel, a rate that can stress water supplies.	• Ensure the availability of water resources, both to support feedstock production and for necessary refining for selected feedstock, without adversely impacting local agricultural needs at macro- and smallholder levels. (P&D) • Select feedstock that best minimizes overall demand on water resources through the production cycle while maintaining effectiveness at the selected site. (P&D)	• Establish a baseline of available water resources in the area. (P&D) • Conduct community surveys to determine the extent of water shortages relative to community needs. (O&M)

FOSSIL FUELS



The International Energy Agency's World Energy Outlook 2012 explore various scenarios for holding Global Climate Change to the goal of no more than a two degree increase by 2050. Under their *Energy Efficiency Scenario* no more than one-third of proven reserves of fossil fuels can be consumed prior to 2050 if the world is to achieve the 2 °C goal.

Source: IEA, Key World Energy Statistics 2012. http://www.iea.org/publications/freepublications/publication/kwes.pdf

OVERVIEW

Fossil fuels are considered nonrenewable resources because they were formed over millions of years from decomposition of ancient plant and animal material in sedimentary rocks under high pressure and do not quickly regenerate once extracted. Coal, natural gas, and oil are the largest sources of global energy needs, and power two-thirds of electricity generation. Most small-scale development activities rely on fossil fuels primarily for operation of machinery, diesel pumps and generators, and for transportation. In fact, in rural settings globally, diesel generator sets are likely the most common source of electricity and diesel is the predominant fuel source for transportation and industry.

Diesel engines and fuel

Diesel engines are one of the main contributors to poor air quality and GHG emissions globally due to their use in vehicles and much of the world's equipment. This will likely continue due to expected increases in the amount of vehicles and vehicle miles traveled globally.

The use of **diesel fuel** for local power generation is common in many development settings, particularly in rural areas and in urban areas where electrical generation from central sources is either non-existent or unreliable.

COAL AND LIGNITE

With the highest carbon content of all the fossil fuels, carbon dioxide emissions from coal and lignite combustion represented 28.3 percent of total U.S. GHG emissions in 2010. The emissions associated with coal and lignite combustion can result in significant adverse impacts to human health such as respiratory illness. In addition to impacts associated with GHG emissions and air pollutants from combustion, coal mining has major adverse effect on landscapes and water resources.

NATURAL GAS

Natural gas is primarily methane. Its emissions have fewer potential impacts on human health and the environment, but its extraction and production still result in significant adverse environmental impacts.

OIL

The greatest use of petroleum globally is for transportation, and accounts for only a small percentage of electricity needs. The absence of significant renewable alternatives in the transportation sector may have long-term adverse impacts on small-scale development, as global oil and gas resources decline and demand and price for these fuels continue to rise.

Liquefied Petroleum Gas (LPG) is a by-product of natural gas processing and oil refining that converts to liquid under moderate pressure. LPG is used as motor vehicle fuel in a liquid mixture, usually called "propane" among consumers. It is also used for cooking, heating, and refrigeration.

TRENDS AND ECONOMICS

According to World Energy Outlook (WEO) 2012 the world is not moving quickly to transition the global energy system onto a more sustainable path. Under the WEO 2012 *New Policies Scenario* (the WEO central scenario), global energy demand is predicted to grow by more than one-third through 2035, with China, India, and the Middle East accounting for 60 percent of the increase. Energy demand is not expected to rise much in OECD countries and this part of the world is predicted to move away from oil, coal, and nuclear energy sources, toward greater utilization of natural gas and renewables. Despite this shift toward low carbon energy options, fossil fuels are still the dominant energy source globally, supported by $523 billion in subsidies in 2011. The *New Policies Scenario* goal is to **prevent further increases in global temperature by more than 2 °C (3.6°F)**, and that to do so will require consuming no more than one-third of current fossil fuel reserves prior to 2050, unless **carbon capture and storage (CCS) technology** were to be implemented on a large scale. Of remaining fossil fuel reserves, two-thirds are attributed to coal, 22 percent to oil, and 15 percent to gas. Two-thirds of these reserves are found in North America, the Middle East, China, and Russia.

NATURAL GAS

In every IEA scenario, demand for natural gas increases. In China, India, and the Middle East, demand is strong, proving that natural gas fares well under varying policy conditions. It is expected that gas will overtake oil use in the U.S. by 2030 due to low prices and abundant supply.

Almost half of the increase in global gas production by 2035 will be accredited to **unconventional gas**[12], mostly from China, the U.S., and Australia. However, unconventional gas industries are still finding their footing, and much uncertainty exists as to how extensive and usable known unnatural gas resource bases are.

WHAT IS THE FUTURE OF COAL?

Worldwide, coal provides 26.6 percent of energy use but emits 43.1 percent of global carbon dioxide. Depending on the strength of policies to favor renewable, lower-emissions energy sources, demand for coal could vary greatly in the next decade. Enforcing efficient coal-burning technology will be crucial, especially in Beijing and New Delhi, where 75 percent of non-OECD coal demand is expected to occur.

ENVIRONMENTAL ISSUES AND MITIGATION MEASURES

A number of the environmental issues the world faces today are due to the dependence on fossil fuels for energy. Fossil fuels produce the largest amount of GHG emissions in the world, mainly by

[12] Unconventional gas requires greater technology and investment to harvest because of its unusual geological locations. The three main sources are shale gas, tight gas, and coalbed methane.

combustion to produce electricity. While adverse effects on air quality and GHG emissions are small from activities at the household or micro-enterprise level, when combined by thousands of households or small enterprises, cumulative adverse air emissions can become quite significant, particularly in urban settings that are subject to inversions.

The following table highlights the environmental impacts associated with use of the above fuels in small-scale development.

DESCRIPTION OF ENVIRONMENTAL IMPACT	MITIGATION MEASURE	MONITORING
COAL AND LIGNITE		
Air Pollution. Coal burning is a leading cause of smog, acid rain, and toxic air pollution. Emissions include the following: **Sulfur dioxide (SO_2):** Coal plants are the leading source of SO_2 pollution, which takes a major toll on public health, including contributing to the formation of small acidic particulates that can penetrate human lungs and be absorbed by the bloodstream. SO_2 also causes acid rain, which damages crops, forests, and soils, and acidifies lakes and streams. **Nitrogen oxides (NOx):** NOx pollution causes ground-level ozone, or smog, which can burn lung tissue, exacerbate asthma, and make people more susceptible to chronic respiratory diseases. **Particulate matter (PM):** Particulate matter (also referred to as soot or fly ash) can cause chronic bronchitis, aggravated asthma, and premature death, as well as haze, which obstructs visibility. **Mercury:** Coal plants are responsible for significant mercury emissions, a toxic heavy metal that causes brain damage and heart problems. Just 1/70th of a teaspoon of mercury deposited on a 25-acre lake can make fish unsafe to eat. Activated carbon-injection technology can reduce mercury emissions by up to 90% when	• When possible, use clean, high efficiency boilers, stoves, and lamps that use renewable energy. (P&D, O&M) • Conduct a predevelopment assessment and/or ESV to ensure that coal burning -- or the best energy alternative -- minimizes impacts to air and water quality (P&D).	• Maintain daily logs of outdoor and indoor air quality. (O&M) • Meter outdoor and indoor air quality continuously at selected locations. Conduct biannual assessments of human respiratory health impacts. (O&M)

DESCRIPTION OF ENVIRONMENTAL IMPACT	MITIGATION MEASURE	MONITORING
combined with baghouses. Other harmful pollutants include toxic heavy metals such as **lead** and **cadmium,** as well as trace amounts of **uranium**. Baghouses can reduce heavy metal emissions by up to 90%. In addition, coal burning produces **carbon monoxide**, **hydrocarbons**, and **volatile organic compounds** (VOCs), which form **ozone,** and **arsenic**.		
Water Resources. If mining occurs locally, there is potential for nearby water bodies to become contaminated.	• Use cement seals to separate and protect surrounding rock, soil, and groundwater. (C) • Conduct a predevelopment assessment and/or ESV to ensure that mining -- or the best energy alternative -- minimizes impacts to water resources (P&D).	• Monitor water table height, the availability of surface water, and its seasonality and quality. (C, O&M)
Waste Management. Residues from combustion and storage of fuel contaminate soil and water bodies nearby.	• Develop and implement protocols for containment and disposal of residues from combustion. (O&M)	• Regularly monitor the waste management process to ensure proper containment and disposal of combustion residues. (O&M)
Land Changes. Where coal is mined locally, land changes from drilling can cause substantial habitat loss and biodiversity loss and interfere with existing land uses.	• Prior to implementation, conduct predevelopment assessments and/or ESV to ensure that land use changes minimize impacts to valuable ecosystem services as well sensitive habitatsand culturally sensitive areas. (P& Replant vegetation or repopulate affected species in areas not directly impacted by mining. (C, P&D)	• Visual inspection at the onset of construction to determine the level of tree cover/incidence of animal habitat. Conduct follow-up inspections throughout the rehabilitation process. (C, O&M)
Health effects. Smoke resulting from heating and cooking can result in cumulative health effects on households, especially on women cooking with these fuels, and also on families that rely on these fuels for house heating. These impacts can likewise extend to the community level, especially during cold winter	• When unable to use clean technology for heating and cooking, build kitchens with porous materials and proper ventilation to improve indoor air quality. (C) • Provide local workers PPE, especially masks, to avoid	• Conduct regular analyses of outdoor and indoor air quality, and investigate human respiratory health impacts. (C, O&M) • Visit worksites bi-annually to ensure PPE and safety practices are used. (O&M)

DESCRIPTION OF ENVIRONMENTAL IMPACT	MITIGATION MEASURE	MONITORING
months when the household use of coal peaks. Where artisanal mining occurs locally, potential health and safety issues may exist for miners.	inhalation of dust and smoke during mining. (P&D, C, O&M)	
Global Warming. GHG emissions from coal combustion at the household level, mainly for heating and cooking, which affects local air quality as well as local and global climate stability.	• When possible, use clean, high efficiency boilers, stoves and lamps that use renewable energy. (P&D, O&M) • Conduct predevelopment assessment and/or ESV to ensure that development changes minimize impacts to valuable ecosystem services -- in this case air quality and carbon sequestration (P&D).	• Take measurements of lifecycle GHG emissions during mining and extraction, and of the end use of the fuel. (C, O&M)
DIESEL		
Water/Soil Contamination. Spillage and vapor releases can occur at pumps, as well as leakage from underground tanks, causing contamination of groundwater, surface water and soil.	• Conduct predevelopment assessment and/or ESV to ensure that development changes minimize impacts to valuable ecosystem services -- in this case soil and water quality (P&D). • Use well-designed concrete pads to capture contaminants in the case of seepage or spills. (P&D, C, O&M, DCM) • Use leak-preventing nozzles at pumps. (C, O&M) • Inspect above and below ground tanks for rusting and poor welds. • Develop and establish protocols for educating workers on appropriate operations and safety. (P&D, O&M) • Establish contractual requirements for decommissioning tanks at the end of their design lives.	• Maintain fuel and O&M logs. Visit worksites bi-annually to check logs and ensure pads and nozzles are preventing and capturing any releases, seepages, or spills. (O&M) • At decommissioning of tanks, ensure containment of all residual liquid fuel.
Air Pollution. Primary pollutants emitted from diesel engines include:	• Use reduced sulfur and aromatics content in fuel, and consider using	• Maintain daily logs of outdoor and indoor air

DESCRIPTION OF ENVIRONMENTAL IMPACT	MITIGATION MEASURE	MONITORING
PM, carbon monixide, NOx, hydrocarbons, VOCs, and other hazardous air pollutants as classified under the Clean Air Act. Information about these pollutants can be found at: http://www.mde.maryland.gov/programs/Air/MobileSources/DieselVehicleInformation/HealthandEnvironmentalEffects/Pages/index.aspx.	zero-sulfur fuels, such as natural gas, in heavy-duty applications. (P&D) • Utilize air pollution control technologies, and hybrid engines and fuel cells. (P&D) • Use exhaust trap retrofits and smoke inspections. (P&D, C, O&M)	quality. (O&M) • Meter outdoor and indoor air quality continuously at selected locations. Conduct biannual assessments of human respiratory health impacts. (O&M)
Health/Safety of Workers. Worker health and safety at storage and filling sites may be affected if PPE is not provided. Exposure to diesel exhaust primarily affects the respiratory system and worsens asthma, allergies, bronchitis, and lung function. There is some evidence that diesel exhaust exposure can increase the risk of heart problems, premature death, and lung cancer.	• Require that workers wear PPE to avoid exposure to diesel exhaust. (P&D, C, O&M)	• Visits worksites bi-annually to ensure PPE and safety practices are used. (O&M)
Global Warming. Where diesel generators are used for local power generation, cumulative impacts from numerous household or commercial/industrial generators can have significant adverse effects on air quality as well as produce notable increases in GHG emissions compared to the emissions produced at fossil-fueled, central power-generating stations. GHG emissions impact local and global climate stability.	• Use alternatives to diesel generators, including biofuel ready systems and fuel cells. An example can be found at: http://www.yorpower.com/renewable-energy.htm. (P&D) • Utilize emission controlling technology. (O&M) • Conduct predevelopment assessment and/or ESV to ensure that development changes minimize impacts to valuable ecosystem services -- in this case air quality and carbon sequestration (P&D).	• Provide calculated estimates of lifecycle GHG emissions. (P&D, O&M)
LIQUID PETROLEUM GAS		
Water/Soil Contamination. Spillage and evaporative emissions can occur during refueling.	• Conduct predevelopment assessment and/or ESV to ensure that development changes minimize impacts to valuable ecosystem services -- in this case	• Ensure proper handling instructions are received. • Conduct regular analyses of soil/water conditions.

DESCRIPTION OF ENVIRONMENTAL IMPACT	MITIGATION MEASURE	MONITORING
	water and soil quality (P&D). • Use sealed tanks and special refueling valves to eliminate evaporative emissions and spillage. (P&D, C, O&M) • Develop and implement protocols for safe handling of LPG during refueling. (O&M)	(O&M)
Air Pollution. LPG is generally a cleaner alternative to many fuels, but its combustion still produces pollutants. Certain toxics, especially nitrogen oxide and carbon monoxide generally have lower emissions than those of gasoline-fueled vehicles, but they still occur. Carbon dioxide emission levels are reduced by up to 40% over those of gasoline-fueled vehicles, but can also still occur.	• Use emission- controlling technology and consider alternative fuel options. (P&D, O&M) • Conduct predevelopment assessment and/or ESV to ensure that development changes minimize impacts to valuable ecosystem services -- in this case air quality and carbon sequestration (P&D).	• Conduct regular analyses of outdoor and indoor air quality and investigate human respiratory health impacts. (O&M)

DISTRIBUTED ENERGY RESOURCE SYSTEMS

Distributed Energy Resource (DER) systems offer a flexible and responsive approach to power supply management. By drawing from a collection of energy sources, DER systems may have lower costs, fewer environmental impacts, and improved security of supply than from large central generating plants.

Picture of a local micro-grid, the Sendai Micro-grid, located on the campus of Tohoku Fukushi University in Sendai City in the Tohoku district in Japan. Source: NTT Facilities. http://en.wikipedia.org/wiki/Distributed_generation

OVERVIEW

DISTRIBUTED ENERGY RESOURCE (DER) SYSTEMS

Distributed Energy Resource (DER) systems generate electricity from many small local energy sources, as a contrast to the traditional system utilizing large, centralized power stations. Often, DER combines a mix of power generation technologies, be they fossil-fuel or renewable, with energy management and storage systems to enable reliable and high-quality energy supply. DER systems can range from 3kW to 50 MW in size.[13]

A Local Wind Generator in Spain, 2010. Photo Credit: Patrick Charpiat. http://en.wikipedia.org/wiki/Distributed_generation

By drawing from "distributed" smaller energy sources, DER allows for the possibility of a cleaner energy mix, resulting in fewer environmental impacts than larger scale power plants. Additionally, the de-centralized system offers the possibility of

[13] Whole Building Design Guide: *A Program of the National Institute of Building Sciences:* Distributed Energy Resourced (DER) by Barney L. Capehart, PhD, CEM College of Engineering, University of Florida. http://www.wbdg.org/resources/der.php

reduced congestion in area transmission lines, as well as enhanced flexibility and responsiveness to actual energy needs.

DER systems can be used for **base load** power generation, in which the DER system provides the primary energy supply for a given area. However, they also have the flexibility of being used as a secondary power source to respond to **peak demand**, when energy needs are highest in a given area. When utilized for peak demand, Because DER systems are not centralized, they are especially useful in responding in specific areas where energy demand is highest while the central plant provides the majority of power to the energy system on the whole.

The **National Renewable Energy Laboratory (NREL)** offers an overview of **Distributed Energy Basics** at: http://www.nrel.gov/learning/eds_distributed_energy.html.

DER TECHNOLOGIES

DER technologies are by design **modular**, designed for flexible utilization. In practice DER systems are also diverse, drawing on renewables or fossil fuels such as diesel, waste oils, and natural gas. Renewables may include wind, solar PV, hydroelectric, and/or biomass.

The below table is adapted from information developed in the California Distributed Energy Resources Guide and describes common technologies used in conjunction with DER systems.

DER TECHNOLOGIES	ENERGY GENERATION	FUEL(S) USED	BENEFITS
Microturbines Small combustion turbines derived from turbocharger technologies found in large trucks or the turbines in aircraft auxiliary power units (APUs). For more information, refer to: Microturbines.	25 kW – 500 kW	Natural gas, propane, diesel, multi-fuel	• Significantly reduce GHG emissions relative to traditional fossil fuel power generation. • Can be used as Combined Heat and Power (CHP) to improve efficiency. • Can provide small-scale (residential or small commercial) heating. • Commercially available and can be purchased in limited quantities. • Can be used flexibly, e.g., to fulfill base load or peak energy demands.
Combustion Turbines Conventional combustion turbine (CT) generators are typically fueled by natural gas, oil, or a combination of fuels.	500 kW – 25 MW (for DER)	Natural gas, distillate, methane	• Very high energy efficiency when used for CHP. • Currently commercially available, with relatively low costs of O&M.

DER TECHNOLOGIES	ENERGY GENERATION	FUEL(S) USED	BENEFITS
Modern single-cycle combustion turbine units typically have efficiencies in the range of 20% to 45% at full load.			• Can be used flexibly, i.e. to fulfill base load or peak energy demands.
Internal Combustion Engines An internal combustion (IC), engine converts fuel energy into mechanical power, which rotates a shaft in the engine to generate power from the rotation.	5 kW – 7 MW	Diesel, natural gas, propane, biogas	• Can provide large power loads in absence of centralized power source. • If used as support power, has fast start-up which prevents the need for Uninterrupted Power Supplies (UPSs). • Mature, commercially available technology. • Highly efficient when used for CHP.
Energy Storage/Uninterrupted Power Supply Systems Do not produce net energy but instead provide electric power for short durations, to stabilize electricity supply.	N/A	N/A	• Commercially available. • Ensure energy supply stability in the event that base load power sources become temporarily unreliable or fail.
Photovoltaic Systems See the discussion on Solar Photovoltaics in the Solar Energy section of this guideline.		None	• No variable costs for fuel. • No moving parts—inexpensive maintenance and long life. • No emissions or noise. • Can be used for peak shaving. • Highly reliable, mature technology.
Wind Systems See the Wind power section of this guideline.	Large Wind Turbines – <1kW - 1,000 kW	None —wind speeds of >12 mph	• No variable costs for fuel. • In utility implementation, zero emissions may allow for a pricing premium for "green power". • Mature technology. • Multiple manufacturers.

DER TECHNOLOGIES	ENERGY GENERATION	FUEL(S) USED	BENEFITS
Hybrid Systems These combine available technologies to improve performance and efficiency of equipment and energy supply. An example of a hybrid system would be a wind turbine using battery storage and diesel-powered backup generators.	Contingent on mix of technologies	Contingent on mix of technologies	Contingent on mix of technologies.

ENVIRONMENTAL IMPACTS OF DISTRIBUTED ENERGY RESOURCE (DER) TECHNOLOGIES

<table>
<tr><th>TECHNOLOGY</th><th>ENVIRONMENTAL IMPACTS</th><th>MITIGATION MEASURES</th><th>MONITORING MEASURES</th></tr>
<tr><td>Microturbines

Efficiency is 28% to 33%</td><td>• Limited adverse on-site environmental impacts</td><td></td><td></td></tr>
<tr><td>Small Gas Combustion Turbines

Efficiency is 25% to 40%</td><td>• Possible need to store fuel on-site
• On-site emissions
• Loud operations</td><td rowspan="2">• Provide training and guidance protocols on proper storage, handling, and disposal of fuels. (P&D, O&M)
• If on-site tank is required, ensure that the tank is double-lined, with a non-permeable “spill zone” to catch accidental spills (e.g. concrete pad). (P&D, C)
• Noise attenuation, e.g., keep engine in muffled room and/or site in an area away from sensitive areas (e.g. schools, hospitals, residencies) when possible. (P&D, C)
• Keep in well-ventilated area. If outside, ensure that is not located near sensitive areas (e.g. schools, hospitals, residencies). (P&D, C)</td><td rowspan="2">• Keep operating logs on fuelling, maintenance and spills. (O&M)
• Conduct noise tests with sample populations prior to construction. (P&D)</td></tr>
<tr><td>Internal Combustion Engines

Efficiency is 28% to 37%</td><td>• Possible need to store fuel on-site
• On-site emissions
• Loud operations</td></tr>
</table>

TECHNOLOGY	ENVIRONMENTAL IMPACTS	MITIGATION MEASURES	MONITORING MEASURES
Photovoltaic	See the discussion of Environmental Impacts in the Solar Energy section of this guideline.		
Large Wind Turbines	See the discussion of Environmental Impacts in the Wind power section of this guideline.		

THE CONCEPT OF CUMULATIVE ENVIRONMENTAL EFFECTS

OVERVIEW

Many human activities may not have significant effects on the environment when evaluated individually; installation of a single pump for groundwater or river irrigation may have little impact on water resources, but a hundred similar pumps in the same area may draw down a groundwater aquifer or significantly lower downstream flows. Similarly one cooking fire in an urban center or refugee camp may not have an individual effect beyond the detrimental health effects on women preparing meals, but multiplied a thousand fold and mixed with vehicular exhaust becomes a serious long-term health hazard.

Increasingly, small-scale development activities that are considered beneficial individually, when combined and interacting with one another, have aggregate impacts that are of local, national and planetary concern. The deterioration of arid lands, the degradation and contamination of agricultural soils, the loss of artisanal fish populations and pollution of rural rivers and streams can be traced to the accumulation and interaction of many individual actions. The growth in our numbers mean that our actions taken together are a major factor behind the alarming rise in GHG emissions, including individual transportation practices and energy use. These effects may differ in nature or extent from the effects of these individual activities. Ecosystems cannot always adapt to the combined effects of human activities without fundamental functional or structural changes.

> ***Understanding Cumulative Environmental Effects***
>
> Cumulative environmental effects should not be seen as a new type of environmental effect. The concept is simply recognition of the complex ways in which the effects of individual projects and activities interact and combine with each other over time and distance. Thus, to address cumulative environmental effects in environmental assessments requires no more than thinking cumulatively. This means considering:
>
> - "The temporal and geographic boundaries of the assessment; and
> - The interactions among the environmental effects of the project, and past and future projects and activities.
>
> To a limited extent, federal and other environmental assessments already address cumulative environmental effects. For example, most examine the baseline environmental conditions, which include the cumulative environmental effects of past and existing projects and activities. However, consideration should also be given to the cumulative environmental effects resulting from the interactions among the environmental effects of the proposed project with those of future projects and activities."
>
> *Canadian Environmental Assessment Reference Guide: Addressing Cumulative Environmental Effects*
> http://www.ceaa.gc.ca/default.asp?lang=En&n=9742C481-1&offset=1&toc=show

Other examples of cumulative environmental effects include the incremental loss of wetlands, deforestation, slash and burn agriculture, the loss of aesthetic landscapes, declines in biodiversity, habitat loss, and the loss of traditional uses of natural resources. In addition, social impacts from these activities may include the displacement or resettlement of indigenous people.

Assessing cumulative environmental effects is now becoming critical at an early stage in the project design process. Although this is recognized by ecologists and environmental scientists, current assessment and management techniques do not always predict or control them adequately.

GLOBAL CLIMATE CHANGE IMPLICATIONS

PLANNING FOR A CHANGING CLIMATE

As the climate continues to change in response to untenable emissions of GHGs, small-scale renewable energy projects offer an opportunity for indirect mitigation against climate change for individuals and communities that often rank among those most vulnerable to climate change's adverse impacts, by curbing GHG emissions and spreading technological awareness and capacity in the use of sustainable energy practices.

At the same time, small-scale renewable energy projects have the potential to be adversely affected by the changing climate they can help stabilize, as fluctuations in local weather patterns in turn influence the very natural resources upon which renewable energy projects rely to succeed.

In the context of EIA, mitigation is the implementation of measures designed to eliminate, reduce, or offset the undesirable effects of a proposed action on the environment.

In the context of climate change, mitigation is an intervention to reduce the sources or enhance the sinks of GHGs in order to limit the magnitude and/or rate of climate change.

ADAPTING TO CLIMATE CHANGE BY MINIMIZING VULNERABILITY THROUGH PROJECT DESIGN

Alterations in cloud cover, wind patterns, local hydrology, soil suitability, rainfall, and temperature are examples of climate changes that could impact the short- or long-term efficacy of renewable energy projects. The vulnerabilities faced in small-scale energy development relate to how the energy sources themselves are influenced by a changing climate:

- **For solar energy projects**, marginal impacts could result from changes in cloud cover, atmospheric water vapor, rainfall, turbidity, and solar irradiance altering the available solar resource globally, or in selected areas.
- For **geothermal projects**, climate change is unlikely to have any discernible impact.
- **Bioenergy feedstock** is susceptible to climate changes such as increases or decreases in rainfall, changes in temperature, or increased prevalence of extreme weather events (e.g. drought or flood). Plant growth could be bolstered by alterations in local weather patterns, increasing available feedstock. Alternatively, water resources could become increasingly scarce threatening water supply for local communities and damaging agricultural production. The USAID Sector Environmental Guideline on Agriculture provides additional detail on the impacts of climate change on agricultural production.
- Climate changes in precipitation and temperature could impact **small-scale hydro** as river flow alterations affect project energy potential. Such risks may be further exacerbated by changes in sedimentation stemming from the reduced (or increased) flow rate, in turn altering the loading potential of reservoirs or the efficiency of turbines. Additionally, extreme weather events such

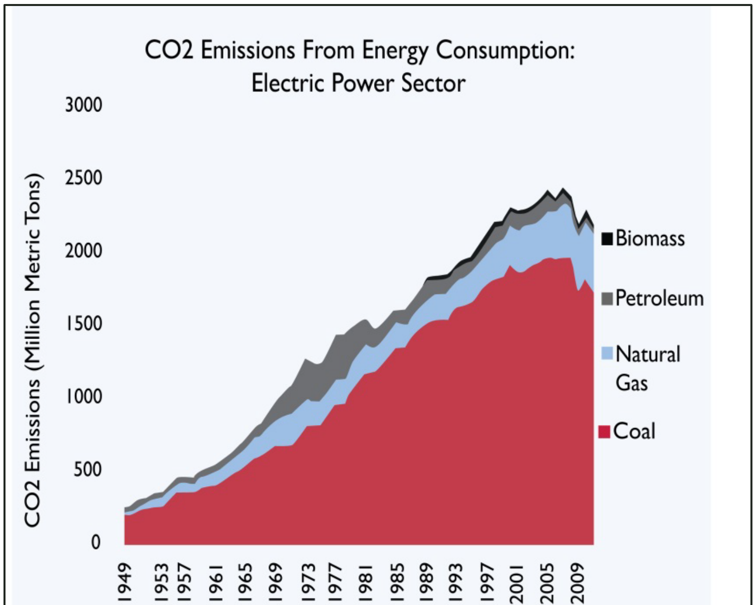
as drought or floods could both have significant, harmful impacts on small-hydro projects – either risking destruction of the project or dramatic reduction in energy potential.

- **Wind energy** projects could be influenced by fluctuations in regional wind patterns, potentially resulting in increases or decreases in local wind resource. Furthermore, extreme weather events such as unusually high wind speeds could pose risk to small-turbine installations.

However, despite the risk of adverse impacts on project efficacy, when implemented with proper planning and consideration, small-scale renewable energy projects have the ability to serve as a significant mitigation measure against the starkest impacts of climate change.

MINIMIZING GREENHOUSE GAS (GHG) EMISSIONS

The potential to reduce global GHG emissions is a fundamental driver in the push to switch away from traditional fossil fuels and toward alternative energy sources such as those discussed in this guideline.



Source: U.S. EPA (Data retrieved November 2013)

At the macro-level, the U.S. EPA estimates that electricity generation accounts for 26 percent of global GHG emissions, of which almost all comes from fossil fuel based electricity. The chart to the right, providing a comparison of carbon dioxide (CO_2) emissions across energy sources in the electric power sector, makes this clear. That said, the downturn in aggregate carbon dioxide emissions from electricity sources between 2007 and 2011 reflects the positive impacts of global trends toward renewable energy sources and cleaner fossil fuel technologies.

In the development context, the global trends toward small-scale renewable energy projects foster further reductions in GHG emissions – either relative to pre-existing area energy sources or alternative electrification scenarios. Small-scale wind and solar energy projects emit few – if any – GHGs. Other renewable energy projects, such as small-hydro and bioenergy, likewise have the potential to support significant reductions, though changes in land use considerations must be properly accounted for when planning activities to ensure that net GHGs are reduced over the life of a given project. Increasingly, off-grid and small-scale renewable energy electrification systems such as solar home systems, RoR small- or micro-hydro schemes, biogas digestion, and small- and medium-sized wind turbines can compete economically with traditional fossil fuel electrification.

COST CONSIDERATIONS FOR PROJECT SUSTAINABILITY

OVERVIEW

Decreases in cost coupled with increases in efficiencies of turbines, photovoltaic panels, bioenergy gasifiers, and geothermal systems are closing the gap between the costs of renewable alternatives and conventional energy systems.

The markets for wind power and solar energy in particular provide optimism for the future of the renewable energy industry. Throughout Africa, wind and solar – as well as hydro – are expected to see major gains. Similar growth is expected in major emerging economies in Latin America (e.g. Brazil) and Asia (e.g. China and India).

However, in less developed markets and at smaller scales the uptake of renewable energy alternatives is stifled by their upfront investment costs, payback periods, reliability, and variability. These concerns affect perceptions of wind power potential and, to a lesser degree, hydropower and solar. To some extent they exist even for developed markets at larger scale.

Perhaps even more pressing is the issue of scalability of renewable energy alternatives. While small-scale projects can effectively meet the needs of an individual, family, store, school, clinic, or community, for projects to be truly sustainable renewable energy alternatives must 1) continue to improve cost competitiveness relative to traditional energy sources and 2) local governments must embrace renewable energy alternatives with supportive policy initiatives.

THE COST OF RENEWABLE ENERGY GENERATION

Beyond the policy environment, in order to effectively evaluate the potential cost of a renewable energy project, project implementers must consider various factors associated with available energy options. Essential factors that implementers must consider include:

- Direct cost of the energy source (e.g. biomass feedstock)
- Quality of the energy source
- Amount of the resource available
- Size of the energy project (How much energy must the project produce initially? Once at scale?)
- upfront capital expenditures (e.g. construction of a power station, purchase of generators and turbines)
- Operation and maintenance costs for machinery
- Cost of labor to construct and operate equipment
- Efficiency of the technology used
- Expected life of project

Depending on site-specific considerations, the costs associated with each of these factors contain an element of variability. For hydro projects, the amount and variability of water resources will vary site by site; value chains may be weak or non-existent, making procurement of some technologies much more expensive than in other locations; biomass feedstock in some countries or regions may grow with much higher energy potential than in others.

The Levelized Cost of Electricity (LCOE) table below provides the LCOE – or cost per kilowatt hour (kWh) of energy generated as of 2013 – for the technologies discussed in this guideline, considering the range of factors discussed above. The LCOE gives the cost estimates as ranges to account for site-based variability of costs.

AN ENABLING POLICY ENVIRONMENT

Existing local policies surrounding renewable energy can play a significant role in a project's long term success. At the smallest scale, this often means ensuring that land-use issues are clearly established *prior* to project implementation; that profit-sharing between investors and small-holder farmers or on-site project managers is properly understood; and the costs to the community for access to electricity (if part of project design) are revealed at project onset.

As projects scale up in size, however, the opportunities for policy support mechanisms increase. Internationally, the most common policy solution to promoting renewable energy are **Feed-In Tariffs**, which establish long-term price agreements designed to compensate households, businesses, or municipalities for the generation of renewable energy. These price agreements tend to be most successful when designed to a) offset the price of renewable energy generation and b) guarantee an additional profit to those producing the electricity. Other successful policy tools have included **renewable portfolio standards**, which require a certain percentage of grid electricity to come from renewable sources, or **direct rebates, subsidies, or tax credits**, which discount the investment cost put toward renewable energy.

The increasing success of small- and large-scale renewable energy projects in emerging markets has the potential to create greater demand for supportive policy environments. Understanding the policies – or systems – in place and the options available can go a long way toward helping foster sustainable energy futures for project beneficiaries.

Levelized Cost of Electricity (LCOE) of Selected Renewable Energy Power Generation Options[14]

RESOURCE	TECHNOLOGY	TYPICAL SIZE OF THE DEVICE (KW)	INVESTMENT (USD/KW)	O&M COST, FIXED ANNUAL (USD/KW) AND/OR (NON-FEED) VARIABLE (US CENTS/KWH)	BY-PRODUCT REVENUE (US CENTS/ KWH)	FEEDSTOCK COST (USD/GJ)	FEEDSTOCK CONVERSION EFFICIENCY (%)	CAPACITY FACTOR (%)	TYPICAL LIFE-OF-PROJECT (YEARS)	LCOE USC/KWH DISCOUNT RATE 3%	7%	10%
Bioenergy	Combined Heat + Power (CHP) (Organic Rankine Cycle)	650-1,600	6,500-9,800	59-80 USD/kW 4.3-5.1 US cents/kWh	7.7	1.25-5	14	55-68	20	8.6-26	12-32	15-37
	CHP (Steam Turbine)	2,500-10,000	4,100-6,200	54 USD/kW and 3.5 US cents/kWh	5.4	1.25-5	18	55-68	20	6.2-18	8.3-22	10-26
	CHP (Gasification Internal Combustion Engine)	2,200-13,000	1,800-2,100	65-71 USD/kW and 1.1.-1.9 US cents/kWh	1.0-4.5	1.25-5	28-30	55-68	20	2.1-11	3.0-13	3.8-14
	Biomass Gasifiers	20-5,000KW	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	8.0-12	N/A
Direct Solar Energy	PV (residential rooftop)	4-100	3,700-6,800	19-110 USD/kW	N/A	N/A	N/A	12.0-20	20-30	12-53	18-71	23-86
	PV (commercial rooftop)	20-50	3,500-6,600	18-100 USD/kW	N/A	N/A	N/A	12.0-20	20-30	11-52	17-69	22-83
Geothermal Energy	Binary-Cycle Plants	1,000-10,000+	2,470-6,100	150-190 USD/kW	N/A	N/A	N/A	60-90	25-30	N/A	7-14	N/A
	Space Heating (Buildings)	100-10,000+	400-1,200	N/A	N/A	N/A	80-90	50-90	25-30	N/A	10-27	N/A
	Ground-source heat pumps	10-350	500-4,000	N/A	N/A	N/A	N/A	25-30	25-30	N/A	7-23	N/A
Hydro Energy	Grid-Based Reservoir/RoR	1,000-10,000+	2,000-4,000	N/A	N/A	N/A	N/A	30-60	40-80	1.1-7.8	1.8-11	2.4-15
	Off-grid/rural (RoR)	0.1-1,000	1,175-3,500	N/A	N/A	N/A	N/A	N/A	40-80	N/A	5.0-40	N/A
Wind Energy	Small-Scale Wind	0/1-100	10,000 (1 kW) 5,000 (5 kW) 2,500 (250 kW)	N/A	N/A	N/A	N/A	20-40	20	N/A	15-20	N/A
	Household Wind Turbine)	0.1-3.0		N/A	N/A	N/A	N/A	20-40	20	N/A	15-35	N/A

Source: REN21 Global Status Report, 2013; IPCC, 2011

[14] LCOE figures are principally taken from Annex III of the IPCC's Special Report on Renewable Energy (http://srren.ipcc-wg3.de/report/IPCC_SRREN_Annex_III.pdf). Where additional information was available, the table was supplemented with data available in Table 2 in Section 2 of the REN 21 2013 Global Status Report (http://www.ren21.net/Portals/0/documents/Resources/GSR/2013/GSR2013_lowres.pdf).

ANNEX I TEMPLATE ENVIRONMENTAL MITIGATION AND MONITORING PLANS

MITIGATION (SEPARATE TABLES FOR DESIGN, CONSTRUCTION, OPERATION AND PHASE OUT)

EXAMPLE: SMALL WIND POWER MACHINES

ENVIRONMENTAL IMPACTS	MITIGATION MEASURE	RESPONSIBLE PARTY	BUDGET
Impact 1: **Threat to Biodiversity:** On-land wind turbines can harm local flying species, particularly birds and bats. They may collide with operating turbines, or be influenced during flight by air pressure fluctuations caused by the spinning blades. Turbines, or their installation, may also alter or destroy animal or plant habitats.	Avoid projects in ecologically sensitive areas (i.e. with endangered bird and/or bat species) whenever possible. Design turbines to account for behaviors of local species (e.g. to be inactive when wind speeds are lower).	(e.g. landscape planner, environmental specialist).	---
Impact 2:	---	---	---
Impact 3:	---	---	---

ANNEX II REFERENCES

MONITORING

EXAMPLE: SMALL WIND POWER MACHINES

ENVIRONMENTAL IMPACTS	MITIGATION MEASURE	MONITORING MEASURE	PHASE	RESPONSIBLE PARTY	BUDGET
Impact 1: **Threat to Biodiversity** On-land wind turbines can harm local flying species, particularly birds and bats. They may collide with operating turbines, or be influenced during flight by air pressure fluctuations caused by the spinning blades. Turbines, or their installation, may also alter or destroy animal or plant habitats.	Select sites with limited, or no, presence of species likely to be affected; avoid projects in ecologically sensitive areas (i.e. with endangered bird and/or bat species) whenever possible. Design turbines to account for behaviors of local species (e.g. to be inactive when wind speeds are lower).	Baseline survey of area species likely to be affected. Number of injured or killed species following project implementation. Develop comparative assessment of available technologies, evaluating why the selected turbine design is the most effective for the area and need.	Planning & Design/Siting Operations & Maintenance Planning & Design	(e.g. environmental specialist) (e.g. environmental specialist) (e.g. lead engineer)	(e.g. $1000)
Impact 2:	---	---	---	---	---
Impact 3:	---	---	---	---	---

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National Communications are submitted by countries to the UNFCCC and include information on country context, broad priority development and climate objectives, overviews of key sectors, historic climate conditions, projected changes in the climate and impacts on key sectors, potential priority adaptation measures, limitations, challenges and needs. http://unfccc.int/national_reports/non-annex_i_natcom/items/2979.php

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