Estimating the Non-Air Environmental Benefits of Renewable Power Sources

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1.0 Introduction

The renewable energy project of the NAFTA Commission for Environmental Cooperation (CEC) was set up to improve regional and national coordination and promote policy coherence on renewable energy issues. To ensure a conducive setting for the renewable energy market to grow, CEC's renewable energy project covers both policy-related as well as technical aspects. Individual tasks are mutually supportive and are aimed at providing information for project developers, investors, decision makers, and others to assist with increasing the use of renewable energy. The Renewable Energy Expert Committee (REEC) provides technical advice to Council and the Secretariat as they implement the tasks.

As part of *Task 6: Develop capacity to calculate the environmental benefits of renewable energy*, the CEC is developing tools for estimating the benefits of renewable energy from different types of renewable energy projects.

Renewable energy sources are often pursued for their minimal local air and global greenhouse gas emissions. This report documents other environmental benefits of renewable energy such as land use, water, and other non-air environmental and health benefits and describes methods used to identify and estimate these benefits. It also identifies gaps in the quantification of these benefits. The report complements work by the CEC on air emissions and GHG benefits and focuses on electric power sources provided by renewable energy.

The environmental and health benefits associated with renewable power sources are primarily related to the avoided negative impacts of using conventional energy sources–adjusted for any negative environmental and health impacts associated with the renewable energy source itself. Methodologies to estimate these benefits therefore involve a comparison of impacts between renewable energy sources and the conventional energy sources that they are most likely to replace.

This study assesses methodologies for comparing renewable and conventional power sources according to several criteria, including:

- Acceptance by stakeholder groups
- Extent and duration of use
- Ease of use
- Accessibility of input data

The study also provides a step by step guide to estimating the benefits of individual renewable energy power projects.

The following renewable power sources are included in the study:

- Wind
- Solar (PV and thermal electric)
- Biomass (excluding combustion of municipal solid or sewage wastes, salt laden wood, or de-inked sludge and spent pulping liquor which are classified as wastes and not renewable sources of energy)
- Biogas from animal wastes or sewage
- Hydro (with storage)
- Hydro (run-of river)
- Wave/Tidal

- Geothermal

The environmental and health benefits of the renewable power sources included in the study are categorized as follows:

- Land
- Water consumption
- Water quality and discharges
- Solid waste and ground contamination (including radiation)
- Biodiversity

The report is comprised of six sections, beginning with this introduction. Section 2 identifies the range of non-air environmental and health impacts associated with conventional power sources. Impacts from renewable power sources are also identified and described. The impacts are classified as zero, low, moderate and high. Quantitative measures are provided where available, and data and information gaps are identified. The results are used to compare renewable and conventional sources for each benefit category, providing a basic method of estimating non-air benefits of renewable power sources.

Fuel cycles for all energy sources in this study include energy resource exploration, production and processing; power generation; and waste disposal. They exclude the manufacture of the power generating equipment.

In Section 3, more rigorous methodologies are explored that can be used to compare environmental and health impacts among energy sources. Examples of how these methodologies have been used to estimate non-air benefits are provided and any gaps in the methodology are identified. Methodologies are divided into three categories:

- Comparative qualitative assessment
- Comparison of quantitative impacts of environmental impacts
- Life cycle assessment

Section 4 describes methodologies that can be used to assign a monetary value to identified benefits or impacts.

Section 5 includes a guide to estimating the non-air benefits of renewable power sources based on the analysis carried out in previous sections.

Section 6 provides conclusions of the study and recommendations for future work.

2.0 Basic Methodology

In this section, the potential non-air environmental impacts of conventional and renewable energy based electricity generation systems are identified. The relative magnitude of each type of impact is evaluated for each generation technology and the comparative benefits of renewable power sources are assessed. This provides us with a basic method for estimating the benefits of renewable power sources.

The following measures are used to assess the five benefit categories:

Land:

- Total area (land take)
- Foot print (area) of equipment and facilities
- Influence on adjacent land
- Degree of concurrent uses
- Long term impacts following decommissioning
- Visual impact

Water consumption:

- Total volume used
- Consumptive use
- Impact on water levels and other water uses

Water quality and discharges:

- Thermal impacts
- Toxic and radioactive discharges or quality changes
- Acidity levels in discharges
- Sedimentation

Solid waste and ground contamination (including radiation):

- Contaminated tailings
- Slag or other solid wastes
- Longevity of impact after decommissioning

Biodiversity:

- Disruption or contamination of habitat and passage
- Impact on indigenous, rare / endangered species
- Introduction of exotic or pest species
- Impact on adjacent land and species

2.1 Environmental and Health Impacts of Conventional Power Sources

The negative environmental and heath impacts of conventional power sources have been well documented, although few quantitative measures of these impacts exist. The non-air impacts of three conventional power sources namely, coal, natural gas and nuclear power are summarized in Table 1. A more comprehensive review of these impacts can be found in Appendix 1. The relative severity (high, moderate, low) of the environmental impacts shown in the table below are based on a comprehensive paper prepared by the US Renewable Energy Policy Project[1] and supplemented by additional information included in Appendix 1. Quantitative measures are provided where available.

It is important to note that impacts may vary greatly depending on regional environmental characteristics and project-specific considerations such as siting, type of land area disturbed, and local ecological characteristics.

Table 1: Potential non-air environmental impacts of several conventional power sources

Power Source	Land Use	Water Consumption	Water Quality/ Discharges	Solid Waste and Ground Contamination	Biodiversity
Coal	**High:** Land disturbed by mining. Open pit mining permanently changes large land areas Direct physical impacts of generation, not including fuel mining estimated to be approximately 5 Ha (19 acres) / MW capacity. Disposal of waste ash 0.4 Ha (1 acre) / MW of installed capacity.	**High:** Water use for fuel washing, power plant cooling, and slag processing. High water use can impact water levels in source water bodies.	**Moderate:** Discharges from mining, fuel processing/ storage, and slag processing contain metals and toxins (arsenic, lead, mercury, etc); potentially significant impacts from acid mine drainage. **High:** Thermal pollution from cooling systems.	**High:** Toxic wastes from mining and slag from power production are produced in significant quantities and contain toxins, metal oxides, alkalis, etc. Slag volume ~ 10% of fuel input. **Low:** Radionuclides in solid wastes.	**High**: Habitat destruction and fish/mammal kills from acid mine drainage, thermal pollution and nitrogen deposition. Elimination of most species in mining areas and impacts on adjacent lands. Habitat impacts throughout fuel cycle.

[1] Serchuk, Adam. "The Environmental Imperative for Renewable Energy: an Update," Renewable Energy Policy Project Special Earth Day Report, Washington, DC (2000). Available online at <www.crest.org/repp_pubs/articles/envImp/04impacts.htm> and <www.repp.org/repp_pubs/articles/envImp/earthday.exec.summ.pdf>

Power Source	Land Use	Water Consumption	Water Quality/ Discharges	Solid Waste and Ground Contamination	Biodiversity
Natural gas	**Moderate:** Drilling and pipeline access to private land. Sour gas development affects adjacent local land uses. Roads for gas development extraction can cause local erosion and affect other land uses.	**Low:** Smaller more distributed plants means less local water consumption. Cooling water requirements higher for combined cycle.	**Zero to Moderate:** Dependant on source of gas; traditional extraction has low impact on water quality. **High:** Coal bed methane extraction can have significant impacts on quality.	**Low:** Disturbance from exploration and drilling.	**Low:** Disruption of local habitats during exploration and extraction. Risk of habitat fragmentation from pipelines.
Nuclear	**Moderate:** Uranium mining, fuel processing, power production and waste disposal eliminate the possibility of using this land for any other purposes for very long periods. Total land take between 0.1 and 0.4 Ha/MW	**High:** Requires large local amounts of cooling water and raises local water body temperatures causing thermal pollution.	**High:** Contamination of groundwater with toxic (acid and radio-active) mining waste water. Routine minor releases of radio-nuclides and heavy metals into surface and groundwater during power generation.	**High:** Acidic and radioactive mine tailings and waste rock. Long lived radio-active used fuel bundles. Large quantities of low level radio-active solid waste. High de-commissioning cost.	**Moderate:** Impacts of toxic and radioactive wastes/ discharges on local land and water species during mining and power generation. **High:** Indeterminate long term genetic impacts.

2.2 Environmental and Health Impacts of Renewable Power Sources

Several studies have identified the potential environmental and health impacts associated with renewable power sources. Potential impacts have also been identified by programs such as Eco-Logo that certify several types of renewable electricity products and the International Hydropower Association that have developed environmental guidelines for hydro-electric power plants that include storage reservoirs. A summary of the non-air negative impacts is provided in Table 2 below for each renewable energy power source. A more detailed discussion can be found in Appendix 2. No relevant sources could be found describing the environmental impacts of biogas, wave or tidal power systems.

Like those for conventional power sources, the relative severity of the environmental impacts shown in Table 2 are based on those developed by the Renewable Energy Policy Project[2] supplemented by the sources listed in Appendix 2. Quantitative measures of impacts are provided where available.

As with conventional power sources, it is important to note that impacts may vary greatly depending on regional environmental characteristics and project-specific considerations.

Table 2: Potential non-air environmental impacts of renewable sources

Power Source	Land Use	Water Consumption	Water Quality/ Discharges	Solid Waste and Ground Contamination	Biodiversity
Hydro with storage	**High:** Dam and reservoir eliminate current uses. However, other concurrent uses may arise from creation of a reservoir.	**Moderate:** Changes in natural water flows. Evaporation from reservoir.	**Moderate:** Changes in water temperature and water quality (e.g. mercury; mercury contamination often temporary but still possibly harmful). Sedimentation in reservoir.	**Moderate:** Reduction in downstream nutrient flow. Increased downstream erosion and river/estuary from modification.	**Moderate:** Potential for disruption of fish habitat and passage. Impact on indigenous, rare / endangered species. Flow disruption may increase spread of exotic or pest species. Downstream impact on biodiversity.
Run-of-river hydro	**Low:** Minor impact from stream diversion.	**Low:** Reductions in natural water flows in bypassed	**Zero**	**Zero**	**Low:** Disruption of fish habitat and indigenous species in

[2] Serchuk, Adam. "The Environmental Imperative for Renewable Energy: an Update," Renewable Energy Policy Project Special Earth Day Report, Washington, DC (2000). Available online at <www.crest.org/repp_pubs/articles/envImp/04impacts.htm> and <www.repp.org/repp_pubs/articles/envImp/earthday.exec.summ.pdf>

Power Source	Land Use	Water Consumption	Water Quality/ Discharges	Solid Waste and Ground Contamination	Biodiversity
		areas			bypassed area.
Solar PV and thermal electric	**High:** Green field projects use significant land but have benign impact on adjacent land Solar PV requires approximately 4.5 Ha/MW. Solar thermal 2-3 Ha /MW. **Zero/Low** No land impact if panels located on buildings or other structures or mounted over land used for other activities (e.g. parking).	**Zero:** For PV systems **Low:** Cooling water demand if solar thermal used.	**Low:** For PV systems; hazardous or toxic substances may be used in production. Most toxic materials are in closed systems during manufacturing process, reducing contamination risk. **Low:** Possible leakage of heat transfer fluid from solar thermal.	**Zero:**	**Zero:**
Wind	**Moderate:** Significant land area but allows some concurrent land/off shore use for rural/agricultural/ marine activities including pivot irrigation. 5-30 Ha/MW total land take depending on project design. 5-10% of that area is typically occupied by turbines. Nuisance to local residents if set backs not sufficient. Visual impact can be significant; erosion may occur from access roads	**Zero**	**Zero**	**Low**: Temporary disruption during construction	**Low:** Minor disruption to avian and local ecosystems depending on site; potentially major impacts if projects poorly sited. Noise impacts not well understood. Risk of habitat fragmentation and travel corridor impacts. Access roads may also contribute to habitat fragmentation.

Power Source	Land Use	Water Consumption	Water Quality/ Discharges	Solid Waste and Ground Contamination	Biodiversity
	depending on siting, geological characteristics. Turbines can be dismantled after the project and the land can be return to near pristine condition.				
Geo-thermal	**Low**: Plant site only 3 Ha/MW total 0.5-1 Ha/MW facility	**Zero:**	**Low:** Possible toxic waste water if source water contains minerals or sulphur	**Zero:**	**Low:** Possible local impact if in a mountainous areas
Marine – wave and tidal	**Low:** Some land disturbance from grid connection of tidal and wave power systems.	**Zero:**	**Zero:**	**Zero:**	**Low:** Local disturbance of habitat in sensitive ecosystems where good tides tend to be.
Biomass	**High:** Competition with land used for food, local energy supply, building materials or medicine production. Varies widely depending on feedstock. 100-400 Ha/MW **Low:** Small impact if agricultural, forest or feed processing waste used.	**Moderate:** Water used in fuel processing and cooling water in power plant. Smaller capacity means lower local impact.	**Moderate:** Fertilizer and pesticide run-off.	**Low:** Non-toxic ash disposal. Slag ~ 2% of fuel input.	**High:** Impact on protected areas or valuable ecosystems. Unsustainable harvesting. Less organic matter returned to soil.

2.3 Comparing Non-Air Impacts of Renewable and Conventional Power Sources Installed Capacity Cost

By comparing the impacts from conventional sources with those from renewable sources for each of the five categories of impacts (described in Tables 1 and 2), we can derive a basic estimate of the non-air benefits of renewable power sources. For example, the land use requirements of nuclear and coal fuel acquisition and power generation are relatively small compared to wind and solar energy for the same power output, but unlike wind and solar this land cannot be used for other purposes and is often contaminated. The land use benefits of wind and solar are therefore related to the multiple uses to which the land used can be put without negative impacts.

Most typical renewable energy power plants are smaller than conventional power plants and typically operate at different capacity factors. Therefore to compare the impacts of any renewable energy power system with those of a conventional power source equivalent capacities need be considered.[3] For example, for a 100 MW wind project with a capacity factor of 36% would be equivalent to 50 MW of nuclear capacity with a factor of 72%[4], and 43 MW of coal capacity with a factor of 85%.

The following sub-sections provide a basic high level discussion of the land use, water consumption, water quality, solid waste and biodiversity benefits of renewable power sources based on the impacts in Tables 1 and 2. For more information on the sources used see Appendices 1 and 2.

In Section 3 a more rigorous approach to estimating these benefits and comparing one benefit with another is described.

2.3.1 Land Use

Total area (land take) and foot print (area) of equipment and facilities

Estimates based on existing projects suggest that while wind farms may occupy between 5-30 Ha per MW depending on project design, only 5-10% of that area is typically occupied by turbines. The United States' National Renewable Energy Lab estimates that actual land required for wind turbines is typically between 0.1 and 0.2 Ha per turbine. In rural areas, the remainder of the area can often be used for non-conflicting uses such as grazing and irrigation.

The Sustainable Development Commission has compared the land area unavailable for other purposes between wind and nuclear facilities.[5] The Commission estimates that the land-take for nuclear power plant is between 0.1 and 0.4 Ha/MW. The Commission estimates that the land-take for an onshore wind power is around 0.180 Ha/MW of capacity, because only a small portion of the total area of a wind farm is actually disturbed land that is not suitable for other uses. Assuming, as noted above, that the capacity factor of a nuclear power plant is typically 72% - about twice that of a wind farm, the actual areas unavailable for other uses per unit of power production are quite similar.

Solar photovoltaic installations require approximately 3.5 Ha/MW of capacity, while solar thermal electricity technologies may require only 1.3 to 2 Ha/MW. Assuming a capacity factor of 20% for solar this

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[3] We have assumed that in future renewable energy plants incorporating power storage systems such as pumped storage and advanced batteries will be able to displace larger conventional plants.

[4] Typical for nuclear power plants in Ontario if unscheduled outages and repairs are taken into account

[5] Sustainable Development Commission. "The Role of Nuclear Power in a Low Carbon Economy: Paper 3 – Landscape, Environment and Community Impacts of Nuclear Power," (2006). Available at <www.sd-commission.org.uk/publications/downloads/Nuclear-paper3-landscapeEnvironmentCommunity.pdf>. Accessed November 2007.

rises to between 5-10 Ha/MW when compared to 72% nuclear capacity factor. However, when PV systems are installed on existing building envelopes, there is no incremental land use area impact.

Coal has a significantly higher land use footprint than either nuclear or wind, but potentially lower than greenfield-sited solar photovoltaic systems when only direct (ie. non-mining land use impacts) is taken into account, and when accounting for capacity factors.[6] Accounting for land-related impacts of different energy sources depends greatly on the assumptions used to calculate total land-use. An illustration of this problem is provided in the many varying estimates of solar land use requirements for one particular North American jurisdictions: Ontario. A report from Ontario non-profit Pollution Probe estimates approximately 20 km^2 per 1,000 GWh of solar power; the Canadian Solar Industries Association estimates approximately 5.1 km^2 per 1,000 GWh, while the Ontario Power Authority assesses a value of 1 km^2 per 1,000 GWh of solar power. There should be some agreement from stakeholders on appropriate values for assumptions such as land-use where possible to ensure impact evaluation results that are acceptable to most parties.

Run of river hydro, biogas, natural gas and geothermal have the smallest land use footprint. The land use footprint of hydro with storage depends very much on location (depth of valley). In most cases, however, the flooded area can be used for alternative purposes such as recreation, as long as proper attention is paid to clearing the land before flooding. Land use associated with electricity from biomass varies widely depending on feedstock and the electricity generation process.

Influence on adjacent land

Coal and uranium mining as well as coal and nuclear power production have a significant impact on the uses of land immediately surrounding the actual area utilized.

Degree of concurrent uses

As noted above, when comparing land use impacts of different power sources it is important to differentiate between the total land area impacted and land area that will not be available for alternative uses. For example, relative to the coal power fuel cycle, wind, solar, wave and tidal power take up much greater land (or water) area but in many cases this area can be used for other purposes, while land that is mined for coal or used for ash and slag disposal can not be used for its original purpose or for many other purposes either.

Long term impacts/use following decommissioning

While smaller in footprint than areas taken up for renewable power sources, land disturbed for coal or uranium mining and land used for nuclear waste or slag disposal cannot be used for any other purpose.

Visual impact

The visual impact of a power source is dependent on the full occupied area, and not just the area taken up by equipment. Wind therefore has the largest physical impact on the landscape per unit of power output. While solar power systems take up a larger area than wind per unit of output, the solar collectors or panels are at ground level and are therefore less obvious.

In conclusion, therefore, renewable power sources tend to have larger but more benign land use impacts than coal and uranium mining, fuel production, and power production. More land area is affected

[6] To produce 6 TWh for 30 years, coal power requires between 873 and 1,473 Ha, while wind power requires 318 Ha. See: Gipe, Paul. Wind Energy Comes of Age. John Wiley & Sons, Inc., Toronto (1995), p. 395.

per unit of power produced and the visual impact is significant, but the level of contamination and long term impact on the land is much lower.

2.3.2 Water Consumption

Non-thermal renewable power sources such as wind, solar photovoltaic, hydro, or wave/tidal power consume no water in the generation of electricity. A lack of quantitative measures of water consumption per MW or GWh for conventional energy sources makes comparisons difficult. The following observations are based on the small amount of data available.

Any thermal power plant that produces steam to generate power will have a cooling water requirement dependent on the steam pressure and heat rate of the generator. Thermal renewable generators such as solar thermal and biomass combustion would therefore use similar amounts of cooling water as conventional coal, natural gas combined cycle and nuclear for generating plants with the same capacity and heat rate. However, renewable energy generators tend to be smaller and more widely distributed and therefore in areas where cooling water is scarce could have lower impact on local water sources.

Mining and processing of coal and uranium requires the use of water, a portion of which is usually consumptive use.

Evaporation takes place from hydro power plants with storage but this is likely smaller per GWh than thermal cooling water consumption.

In general therefore, renewable power sources have the benefit of zero or low local water consumption relative to conventional plants.

2.3.3 Water Quality and Discharges

No quantification measures were found for the water quality impacts of renewable or conventional power systems that would allow the quantitative estimation of the benefits of renewable sources. However, the following observations can be made from available information.

Negative impacts on water quality result from pollutants and significant changes in water temperature. Cooling systems for large thermal electric plants like coal, combined cycle natural gas, and nuclear can have significant adverse impacts on local water temperature. Some plants are responsible for the death of more than one million fish per operating year largely due to water temperature increases. Smaller distributed natural gas, and thermal biomass and biogas plants will have less local impact on water temperature as long as they are located on similar size water bodies.

Discharges from coal mining, fuel processing and slag processing can contain metals and toxins (arsenic, lead, mercury, etc). Uranium mining can contaminate groundwater with toxic (acid and radio-active) mining waste water. Nuclear power plants also routinely release minor amounts of radio-nuclides through cooling water into surface and groundwater during power generation.

Renewable power sources like wind and solar in general produce no contaminated water discharges and therefore provide significant benefits over coal and nuclear.

Hydro power facilities with storage can adversely impact water temperature, although typically these temperature fluctuations are far less severe than those that result from cooling systems in thermal electric plants. Hydro power facilities can also result in increased mercury concentrations in water, as flooded soils and rocks containing mercury releases it into the water. Reservoir-based hydro systems can also result in the deposition of considerable amounts of sediment in the reservoir, which can result in varying degrees of impact on water quality and acidity if not addressed effectively.

Geothermal sources may contain high mineral or acid content.

Energy crops grown for biomass fuel water quality impacts are low as long as fertilizer and pesticide run-off is minimized or organic or other ecologically sound practices are used.

2.3.4 Solid Waste and Ground Contamination

As with other types of benefits, there are very few metrics to quantify solid waste impacts or benefits of power sources.

Coal facilities produce ash equivalent to nearly 10% of the fuel input. Biomass plants ash rates are typically much lower, with less than 2% of fuel input remaining as ash after combustion. In the United States, as much as one third of ash from coal combustion has other productive uses, while the remainder is generally landfilled. Coal ash can contain significant concentrations of heavy metals and other toxic materials, including arsenic, cadmium and lead, while biomass ash is generally non-toxic or contains only minute quantities of toxic materials.

Fuel cycle impacts from coal or uranium mining are often much more significant in terms of solid waste generation and ground and soil contamination than the impacts from the actual generation of electricity. For each unit of fuel mined, hundreds or even thousands of units of waste rock are produced. A waste management problem then results, as the waste rock has the potential to adversely impact soil quality.

Nuclear solid waste is of particular concern. While the volume of waste from the nuclear fuel and generation cycle is by volume relatively limited, its highly radioactive nature presents significant waste management challenges. The Pembina Institute has undertaken an extensive review of the environmental impact of Canada's nuclear power capacity.[7] Uranium mill tailings and waste rock from processing are acidic or potentially acid generating, and contain a range of long-lived radionuclides, heavy metals and other contaminants. 90–100,000 tonnes per year of tailings are produced per year to provide fuel for Canada's 15000 MW of nuclear capacity. Approximately 85,000 waste fuel bundles are generated by Canadian nuclear reactors each year. As of 2003, 1.7 million bundles were in storage at reactor sites. It is estimated that these wastes will have to be secured for approximately one million years for safety, environmental and security reasons. Approximately 6,000 tonnes of lower level radioactive wastes are generated each year in Ontario as a result of power plant operations, maintenance, and refurbishment. [8]

In conclusion, therefore, renewable power sources appear to have significant solid waste and ground contamination benefits relative to coal and nuclear power systems, particularly because of the elimination of mining wastes, slag and long lasting radio-active wastes.

2.3.5 Biodiversity

No metrics were found to quantify the biodiversity impacts or benefits of power systems. The following are some observations from available sources.

It is important to note that type and extent of land-use disturbance, discussed in section 2.3.1 above, has significant implications for wildlife and biodiversity. Negative impacts on biodiversity can result from habitat disturbance and/or wildlife activity disruption. Coal mining in particular can disrupt considerable land area and fragment habitat, creating barriers between adjacent habitat zones. Additionally, aquatic

[7] Nuclear Power in Canada: An Examination of Risks, Impacts and Sustainability. The Pembina Institute (2006). <www.pembina.org/pub/1346>

[8] Low-level radioactive wastes include building materials, tools and other items that have become routinely contaminated through use in a nuclear power plant.

ecosystems can be adversely impacted by mining effluent, including acid mine drainage from waste rock and mine tailings.[9]

All thermal electric plants with cooling systems can cause fish and other aquatic life mortality if they are crushed against intake filters, or water temperatures become excessive. The same is true for intakes on hydro power systems.

In general, renewable power plants that meet sustainability guidelines have very few impacts on biodiversity compared with coal and nuclear.

Wind power located in bird migration paths can have impacts on avian mortality from collision with turbines. Environmental assessments to identify optimal locations can help to mitigate or eliminate significant impacts on bird and bat populations. The type, location, and operational schedules of turbines all influence bird and bat fatalities, In the U.S., bird deaths caused by wind turbines are currently just a small fraction of total anthropogenic bird deaths— estimated at less than 0.003% of the total in 2003.

Hydro power, both run of river and hydro projects with storage, can adversely impact aquatic life by disrupting fish habitat.

Biomass and biogas plants that use waste as a fuel source will not have a major impact on biodiversity as long as agricultural wastes are not taken from fields instead of incorporating them in the soil and therefore reducing soil organic matter, or forest wastes are not the result of unsustainable logging practices.

[9] Although air emissions are not considered in this assessment, it is important to note for comparative purposes, that hazardous air pollutants produced from the combustion of coal can negatively affect wildlife populations. These pollutants can significantly impact habitat quality, food availability and animal health. A comprehensive comparison of the environmental impacts of different energy sources should consider toxic air emissions, including heavy metals, and those that contribute to acid rain such as sulphur and nitrogen compounds.

3.0 More Rigorous Methodologies

In Section 2 we showed that quantitative estimates for comparing the negative impacts of different power sources on the five non-air impact areas covered in this study are not widely available, but some high level estimates of the benefits of renewable power sources can be made. In this section we review a number of more rigorous methodologies that are available for measuring and ranking the negative impacts and benefits associated with alternative power sources including those methodologies that can be used when only qualitative estimates are available. These methodologies also allow benefits to be ranked against each other, and can allow for the assessment of trade-offs between one benefit and another.

The methodologies reviewed in this study have been divided into three categories as follows:

- Comparative qualitative assessment;
- Comparison of quantitative impacts of environmental impacts;
- Life cycle assessment.

These methodologies are reviewed against the following criteria:

- Extent and duration of use;
- Acceptance by stakeholder groups;
- Ease of use;
- Accessibility of input data.

3.1 Comparative Qualitative Assessment

3.1.1 Multi-Criteria Decision Analysis

Multi-Criteria Decision Analysis (MCDA), also referred to as Multi-Criteria Decision Making or Multi-Attribute Analysis, is a method of comparing different options on the basis of numerous and potentially conflicting criteria. MCDA often relies significantly on value-laden judgments to determine criteria and weighting. In the absence of agreed quantification measures, the process can still be useful in capturing comparative environmental benefits that other quantitative methods may overlook. MCDA methods are particularly well suited to dealing with highly complex problems with a number of variable and conflicting criteria, and can integrate qualitative and quantitative considerations.

MCDA is a flexible family of methods that can be applied for all kinds of impacts; be made site-/time-specific or not; and can be applied quantitatively or qualitatively. While the relationship to the criteria in terms of positives and negatives of various alternatives may not be possible to quantify, evaluators in an MCDA can still rank the alternatives in terms of achievement or in other ways (i.e. using outranking methods as described below) display the best or worst alternative and hence provide at least an idea of where each option falls relative to the others on a continuum. There can be significant disagreement between methods and it is possible for great differences in results to occur in two related applications of MCDA for the same analysis. However, the purpose of an MCDA is not necessarily to come up with one definitive answer, but also to act as a learning process and a process of discovering biases or differences in values that may not be as visible in other impact assessment methodologies.

Some particular widely used MCDA methodologies that could be applied to the analysis of non-air impacts are profiled below.[10] There is no "best" method and the method chosen essentially depends on a) the type and extent of criteria to be assessed; b) whether the analysis is relative / comparative, a ranking system, or has a different aim; c) types and quality of data available. [11],[12]

- Analytic Hierarchy Process (AHP).

The widely-used AHP method consists of three phases that stem from three guiding principles: "1) the principle of 'constructing hierarchies'; 2) the principle of 'establishing priorities'; 3) the principle of 'logical consistency'".[13] Criteria are separated into a grouped hierarchy. Pair-wise comparisons are used to establish weighting of different criteria within particular hierarchies.

- Preference Ranking Organization Method of Enrichment Evaluation (PROMETHEE).

PROMETHEE is an accessible outranking method of low complexity. It relies on ranking different options and is best applied in situations where a finite number of actions can be evaluated through conflicting criteria. The PROMETHEE process involves pair-wise comparison of alternatives under a *coherent set of criteria*.[14]

- Novel Approach to Imprecise Assessment and Decision (NAIADE).

NAIADE is a recently developed Multi-Attribute Analysis method, where there is no explicit weighting of criteria. This method allows the use of information impacted by different types of uncertainty. This method involves the pair-wise comparison of options, aggregation of criteria and subsequently the evaluation of options.

Extent and duration of use

MCDA has been applied in fields as diverse as energy management, military planning, and human resource management.[15] The New Approach to Appraisal framework, developed to appraise transportation projects in the UK, is an example of a major practical application of MCDA. The Netherlands and its municipalities have also applied MCDA in "interactive" policymaking approaches at the national, regional, and local scale in city and infrastructure planning.[16] MCDA has previously been used as an approach for

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[10] For more on the application of Multi-Attribute Analysis to energy systems, see Cavallaro, Fausto. An Integrated Multi-Criteria System to Assess Sustainable Energy Options: An Application of the Promethee Method," FEEM Working Paper No.22 (2005). See <papers.ssrn.com/sol3/papers.cfm?abstract_id=666741>

[11] For some guidelines in selecting an MCDA method, see Guitouni, Adel and Jean-Marc Martel. "Tentative guidelines to help choosing an appropriate MCDA method," European Journal of Operational Research, no. 109, no. 2 (1998).

[12] See also Triantaphyllou, Evangelos. Multi-Criteria Decision Making Methods: A Comparative Study. Springer, 2001.

[13] De Montis, Andrea et al. "Criteria for Quality Assessment of MCDA Methods," Third Biennial Conference of the European Society for Ecological Economics. (2000).

[14] Cavallaro, Fausto. An Integrated Multi-Criteria System to Assess Sustainable Energy Options: An Application of the Promethee Method," FEEM Working Paper No.22 (2005). See <papers.ssrn.com/sol3/papers.cfm?abstract_id=666741>

[15] Martel, Jean-Marc. "Multicriteria Decision Assessment: Methods and Applications," CORS-SCRO, Annual Conference, Windsor, Ontario (1999). Available at <www.cors.ca/bulletin/v33n1_1e.pdf>. Accessed November 2007.

[16] Monnikhof René A.H. and Pieter W.G. Bots, "On the application of MCDA in interactive spatial planning processes: lessons learnt from two stories from the swamp," Journal of Multicriteria Decision Analysis 9, no.1-3 (2000).

assessing the overall impacts of renewable energy, in some cases including considerations of non-air environmental impacts.[17],[18],[19]

Acceptance by stakeholder groups

Because MCDA is extremely flexible, it lends itself well to early involvement of a wide variety of stakeholder groups in determining appropriate assessment criteria and the weighting of those criteria. This process is used commonly as a tool in participatory decision-making.[20]

Ease of use and accessibility of input data

The inputs that can be used in MCDA can be qualitative or quantitative. Because of the flexibility of MCDA, as a comparative method it lends itself well to structuring an analysis around what data is available. Assessments can be based on data compiled for environmental impact assessments or other project assessments in the case of particular project comparisons, and can include a wide range of inputs depending on the objectives of those carrying out the analysis. Because of the flexibility of this method, its ease of use generally depends on the complexity of the particular approach decided on by stakeholders.

Some particular MCDA described above do have standardized data sources for assessing impacts, and software-based methods can make standardized comparisons quite simple. However, few if any of these particular methodologies adequately address non-air impacts of power sources in their analyses.

3.2 Quantitative Estimates of Environmental Impacts

3.2.1 Externality Analysis

Though Multi-Attribute Analysis methodologies can provide valuable insight on the comparative impacts of different energy sources, they do not generally allow for a direct mechanism of determining the economic value of the various comparative impacts. Scholarly literature suggests that perhaps the most significant initiatives being undertaken to assess the monetary valuation of environmental impacts involve methodologies related to externality assessments. Assigning monetary values to externalities can allow for more market-based signals and mechanisms that account for these costs – see also Section 4 below.

An example of an externality analysis might be the specific methodologies and data provided through the European ExternE program, which provides a common basis for comparison of the emissions-related impacts of energy production.

Extent and duration of use

Externalities analyses are frequently used by private industry, local authorities, and national and regional governments to inform decision-making processes.[21] Externality assessments have been carried out for at least a decade in the United States, with regulatory impact assessments attempting to approximate environmental and health impacts of emissions. In Europe, ExternE in particular has influenced legislation

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[17] Cavallaro, Fausto. An Integrated Multi-Criteria System to Assess Sustainable Energy Options: An Application of the Promethee Method," FEEM Working Paper No.22 (2005).

[18] Greening, Lorna and Steve Bernow. "Design of coordinated energy and environmental policies: use of multi-criteria decision-making," Energy Policy 32, no. 6 (2004).

[19] Diakoulaki et al. MCDA and Energy Planning in Multiple Criteria Decision Analysis: State of the Art Surveys, eds. Fiqueira, Jose et al. Springer (2004).

[20] Monnikhof René A.H. and Pieter W.G. Bots, "On the application of MCDA in interactive spatial planning processes: lessons learnt from two stories from the swamp," Journal of Multicriteria Decision Analysis 9, no.1-3 (2000).

[21] Holland, Mike. « Applications of the ExternE Methodology," AEA Technology (2001). Available at <arirabl.com/publications/myPapers/PollAtmos/ApplicExternE-PollAtmos.pdf>. Accessed November 2007.

on environmental and emissions standards. Studies using ExternE have been commissioned by the European Commission, the United Nations Economic Commission for Europe, and by the government of the UK.[22]

Acceptance by stakeholder groups

Research indicates that in order to gain acceptance from stakeholder groups, methods for undertaking externalities analyses should be consistent, comprehensive, and transparent.[23]

Ease of use and accessibility of input data

Externality assessments generally require fairly accurate and specific data. For European countries, ExternE provides useful information on emission impacts of particular energy sources disaggregated by region. However, no equivalent database of quantitative non-air impacts exists, nor is there an analogue for ExternE in place for North America.

3.2.2 Environmental Impact Assessment

Environmental Impact Assessment (EIA) is the process of identifying and evaluating the environmental consequences of an activity. EIA is used as an aid to public decision making on larger projects, and is used frequently in the evaluation of power plants. General best practices have been developed for EIA processes, although the process differs greatly from jurisdiction to jurisdiction where it is used.[24]

EIA guidelines vary depending on the guiding framework within which they occur (for example, EIAs undertaken under the National Environmental Policy Act in the United States are carried out differently than in Canada).

Why EIA is relevant to this report is that while the focus of an EIA is often on a single project, the core of the assessment is the alternatives section.[25] The alternatives section of an EIA presents the environmental impacts of the proposed project and compares those impacts against available alternatives. However, the suitability of most EIA processes for determining the environmental impacts of electricity sources is extremely limited, as most alternatives explored in EIAs represent minor variations of the project being studied rather than a range of viable, distinct alternatives.

EIA is a widely accepted process required by many governments worldwide for the analysis of certain types of projects. Although particulars of EIA methods vary, Canada, the United States and Mexico all have established EIA procedures in place to assess new projects. Many other stakeholder groups in North America, including ENGOs, participate in the EIA process.

3.2.3 Ecological Impact Assessment

A more particular type of EIA, an Ecological Impact Assessment (EcIA) tends to predict and evaluate impacts of a process or specific project on ecosystems and their components and does not focus as much on

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[22] Holland, Mike. « Applications of the ExternE Methodology," AEA Technology (2001). Available at <arirabl.com/publications/myPapers/PollAtmos/ApplicExternE-PollAtmos.pdf>. Accessed November 2007.

[23] Clarke, Lee B. "Externalities and Coal-Fired Power Generation," Atmospheric Environment 31, no. 9 (1997).

[24] International Association for Impact Assessment. « Principles of Environmental Impact Assessment, » International Association for Impact Assessment, Fargo, North Dakota (1999). Available at <www.iaia.org/modx/assets/files/Principles%20of%20IA_web.pdf>. Accessed November 2007.

[25] "[The alternatives] section is the heart of the environmental impact statement," from NEPA, part 1502 of the Environmental Quality Improvement Act of 1970, as amended (42 U.S.C. 4371 et seq.), sec. 309 of the Clean Air Act, as amended (42 U.S.C. 7609), and E.O. 11514 (Mar. 5, 1970, as amended by E.O. 11991, May 24, 1977).

economic or social impacts. Tools for assessing ecological impacts are currently being developed within the context of the Convention on Biodiversity.[26] Guidelines for the consideration of biodiversity in impact assessment have been published through the Commission for Environmental Assessment.[27] For impacts occurring at specified sites methods may be (and have in practice been) adopted from project EIAs.[28] Broader impacts of the energy sector, specific site data will not be available, and assessments in the context of the EcIA will likely rely on classification of affected landscape types and a broad estimate of what effect a particular activity could have in a range of ecosystems. Indicator species have been used in some methodologies to achieve a broader analysis through EcIA.[29]

3.2.4 Environmental Risk Assessment

Risk and risk assessment processes both involve an evaluation of the probability that damage or adverse effects will occur as a result of a given activity or decision. [30]

Risk assessment is a broad term covering many different types of assessments. Relevant to this particular report, risk assessment can be made either on the basis of chemical substance release – often planned as part of an activity – or accident potential – unplanned events that could have negative impacts. The latter may include environmental aspects.[31]

Protocols for risk assessment of chemicals have been developed internationally. For risk assessment of chemicals, generally accepted practice includes an exposure assessment capturing the size and nature (i.e. vulnerability) of those exposed to releases, as well as the magnitude and duration of the exposure.[32]

In accident risk assessment, accident consequences and their frequency are estimated. The assessment is usually divided into three parts: hazard identification, consequence analysis and frequency estimation.[33] For hazard identification, a number of relatively simple methodologies have been developed to aid system experts to identify hazards, e.g. Hazards and Operability Analysis (HAZOP). For the assessment of risk consequences, a number of methods quantify impacts due to accidents are available.[34]

Risk assessment of accidents is typically done prospectively for different types of projects, and it is typically site-specific. Risk assessment of chemical substances can be site-specific but also more site-independent for a region or a nation. It typically includes all emissions of the substance within the geographical boundary or from a particular project or plant. Comparisons can either be made between

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[26] Therivel, Riki and Stewart Thompson. Strategic environmental assessment and nature conservation. English Nature, Peterborough (1996).
[27] Slootweg, Roel et al. Biodiversity in EIA & SEA: Voluntary Guidelines on Biodiversity-Inclusive Impact Assessment. Commission for Environmental Assessment (2006). Available at <http://www.cbd.int/doc/publications/cbd-ts-26-en.pdf>. Accessed May 2008.
[28] Wathern, Peter. "Ecological impact assessment," in Petts, J. Handbook of Environmental Impact Assessment, Volume 2. Oxford, Blackwell Science (1999). P. 326-346.
[29] Treweek, Jo. Ecological Impact Assessment. Blackwell Science, Oxford (1999).
[30] Pons, Marie-Noelle and Thomas Gigerl. "Evaluation Tools," University of Nancy, France. Available at <www.ensic.u-nancy.fr/COSTWWTP/Pdf/Tomar_wg3.pdf>. Accessed November 2007.
[31] Finnveden, Goran and Asa Moberg. "Environmental Systems Analysis Tools," Journal of Cleaner Production 13, no. 12 (2005).
[32] Finnveden, Goran and Asa Moberg. "Environmental Systems Analysis Tools," Journal of Cleaner Production 13, no. 12 (2005).
[33] Verheem, Rob and Jos Tonk. "Strategic Environmental Assessment: One Concept, Multiple Forms," Impact Assessment and Project Appraisal 18, no. 3 (2000).
[34] Finnveden, Goran et al. "Strategic Environmental Assessment Methodologies – Applications within the Energy Sector," *Environmental Impact Assessment Review 23*, no. 1 (2003).

different alternatives (which alternative poses the greatest risk?) or against a standard (is the risk acceptable or not?). Comparisons can also be made internally within a system to identify the greatest risk. Risk assessment of chemicals is typically done quantitatively. Risk assessment of accidents can be carried out both quantitatively and qualitatively.

While risk assessment does not on its own provide an effective basis for the comparison of non-air impacts of power sources, it can be used as a component of other methodological approaches such as MCDA to account for risk.

Extent and duration of use

Risk assessment has been in use for several decades, with the Food and Drug Administration in the United States applying risk assessment for the purposes of food regulation. Risk assessment protocols have been used to compare human health impacts of different power sources,[35]

Acceptance by stakeholder groups

Variance and uncertainty are major factors in carrying out risk assessment. For risk assessment based on one-time accidents, developing quantitative factors for particular risk characteristics can be a highly subjective process and result in a lack of acceptance from certain stakeholders.

Ease of use and accessibility of input data

The ease of use in risk assessments and accessibility of input data depends largely on the scope and type of assessment undertaken, with accessibility of input data varying widely depending on whether an assessment is analyzing qualitative or quantitative factors in the determination of risk.

3.3 Life Cycle Assessment

Life-Cycle Assessment (LCA) is a method of estimating the environmental performance of products or services based on all stages of their production, use and disposal. There are different methodologies for completing a LCA, but there are universally common elements to each process outlined by the International Organization for Standardization (ISO) in ISO Standard 14040. When appropriate data is available, certain LCA methodologies can help to carry out an 'apples-to-apples' comparison of particular activities, products or processes in the context of total environmental impacts.

According to ISO standards, LCA should generally be comprised of four primary steps:

1. Goal and scope definition.
2. Inventory analysis, which involved identification and quantification of inputs and outputs.
3. Life cycle impact assessment (LCIA), which aims to determine the degree and significance of potential environmental impacts. This phase is divided into three parts:
    a. Identification and selection of impact categories, indicators, and models to assess the influence of different inputs and outputs on the impact categories.
    b. Assignment of inventory data to impact categories.
    c. Quantification of contributions from the process to the impact categories.
4. Interpretation, where the findings of the inventory analysis and LCIA are assessed the context of the goal and scope of the study as defined in Step 1.

[35] Tianshan Ren et al. "Comparative Health Risk Assessment of Nuclear Power and Coal Power in China, *Journal of Radiological Protection* 18 (1998). 1998.

Not all types of environmental effects are equally well addressed by LCAs.[36] Land-use impacts have historically been difficult to assess, although there has been a considerable methodological development during recent years.[37] Gaps in data can make it difficult to include estimates for all potential impacts, as LCA is focused on quantitative estimation. Effects associated with radiation, accidents and adverse impacts on amenities are typically not covered or not adequately addressed in LCAs, but this may vary based on the scope of the LCA and whether the LCA method used considers long-term or "legacy" impacts. Most LCA methodologies as currently designed are best equipped to assess air emissions impacts, such as life-cycle greenhouse gas emissions for a process or product. Because of their primarily quantitative focus, LCAs also tend to be a relatively site-dependant tool.

LCA has a few other prominent limitations, although these limitations may be surmountable with proper LCA method design. It is difficult to include varying spatial and temporal characteristics of certain processes.[38] Characteristics with varying temporal qualities are often omitted due to the difficulty of their inclusion in typical LCA analyses.

LCA Methodologies

While not all of the methodologies below are directly applicable to the analysis, each has relevant elements that may be useful in differentiating between the degree and type of non-air impacts of different energy sources.

- Life-Cycle Value Assessment [39]

Life-Cycle Value Assessment (LCVA) is a methodology that has been developed over the past 10 years by the Pembina Institute in collaboration with several energy companies. LCVA is based on a similar methodology as the overarching LCA concept, but has two distinct differences:

1. LCVA considers not only life-cycle environmental impacts, but life-cycle economic and social impacts as well.
2. LCVA streamlines the data collection and analysis process by allowing for assumptions to be made that introduce an acceptable level of uncertainty into the process, but allow useful results to be obtained within available time and resource constraints.

- Eco-indicator 99 [40]

Eco-indicator 99 is a widely-used proprietary damage-oriented LCA methodology developed by Product Ecology Consultants in 1999. Using the Eco-indicator 99 method, scores can be calculated for various processes. The Eco-indicator 99 scores are based on an impact assessment methodology that transforms input data into damage scores in the context of damage to human health, ecosystem quality, and resources. This methodology is capable of assessing environmental damages to ecosystem quality and human health caused by land-use and certain emissions to water and soil. The Eco-indicator 99 inventory

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[36] Finnveden, Goran et al. "Strategic Environmental Assessment Methodologies – Applications within the Energy Sector," *Environmental Impact Assessment Review 23*, no. 1 (2003).
[37] Lindeijer, Erwin." Impact Assessment of Resources and Land Use," chapter 2 in Life-Cycle Impact Assessment: Striving Towards Best Practice, eds. Udo de Haes, Halias et al. SETAC (2002).
[38] Udo de Haes, Helias et al. "Three Strategies to Overcome the Limitations of Life-Cycle Assessment," *Journal of Industrial Ecology* 8, no.3 (2006).
[39] http://www.lcva.ca/
[40] http://www.pre.nl/eco-indicator99/default.htm

allows for the assessment of emissions to water and soil from many different substances. Several notable gaps in this methodology exist, such as an inability to assess acidification and eutrophication occurring as a result of waterborne emissions.

Many of Eco-Indicator 99 methodologies calculate damage and non-air impacts of different substances / processes. For example, they provide a calculation procedure for damages caused by human intake of heavy metals through drinking water.

- CML 2002 [41]

Developed by the Institute of Environmental Sciences at the University of Leiden, the CML is a problem-oriented approach, which provides a guide that lists impact assessment categories.

The CML approach relies on a common database of impact factors. Presently, many factors required for the comparison of non-air impacts of energy sources are missing, but are planned for inclusion in future iterations of the CML methodology. These include factors related to land-use, acidification, nitrification, and ionising radiation.

Current factors in the CML 2002 database do not allow for adequate comparison of electricity sources on a non-air impact basis, although addition of new factors may change this in the near future.

Ease of use and accessibility of inputs

Because of the proprietary nature of the Eco-indicator 99 system and its accompanying software and data sets, costs can be a barrier for those who have not purchased the system. However, because it is a software based system based on a common database of impact factors, the system is potentially quite easy to use. These drawbacks are common to most proprietary LCA evaluation systems.

The primary difficulty in the accessibility of inputs is that when desired comparison factors or criteria are missing from the system, it may be difficult or impossible to include them in an analysis.

Acceptance by Stakeholder groups

Again, due to the proprietary nature of the system and its software and data, transparency may be difficult to achieve in the undertaking of an LCA. Stakeholders may not be satisfied with the inability to assess data and assumptions used in the Eco-indicator 99 methodology.

3.4 Comparing Methodologies

While Life Cycle Analysis, Externality Assessment, and Multi-Criteria Decision Analysis methodologies each aim at somewhat different ends in the determination of the comparative value of a number of options, the methodologies do have areas of overlap. Each approach has weaknesses and strengths. By combining the three approaches, with LCA as a subset of MCDA and EA it is possible to capture the benefits of each approach while mitigating their limitations. Such combined analyses are possible, and have previously been carried out successfully in the assessment of the sustainability of electricity systems.[42],[43]

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[41] http://www.leidenuniv.nl/cml/ssp/

[42] Dones, Roberto. "Sustainability of Electricity Systems LCA applied in External Cost and Multi-Criteria Assessments," *Proceedings of the Seventh International Conference on EcoBalance* (2006).

[43] Berring, Simon and Dana Ung. "A Methodology for Environmentally Informed Decision-Making: Towards Sustainable Projects," Centre for Integrated Facility Engineering (2003). Available at <cife.stanford.edu/online.publications/WP083.pdf>. Accessed November 2007.

Another useful study compared the external costs calculated for a number of power plant types with the outcome of a multi-criteria analysis in which environmental impacts are expressed in physical terms or on a qualitative scale. [44] Similarities and disparities in the obtained rankings were identified and clarified on the basis of the fundamental principles of the two approaches. The study concluded that, although external costs do not accurately reflect the traditional value system of individual decision makers, they give suitable price signals and thus help in eliminating distortions of the current energy market. The study also showed that multi-criteria analysis itself is a relatively effective way of ranking environmental attributes of various energy sources, including non-air benefits.

In the context of this study, where very few quantitative estimates of impacts are available, multi-criteria assessment appears to be the only methodology that could currently be used effectively to estimate the non-air benefits of renewable power sources.

[44] Mirasgedis, Sebastianos and Dzidonu Diakoulaki. "Multi-criteria Analysis vs. Externalities Assessment for the Comparative Evaluation of Electricity Generation Systems," *European Journal of Operational Research* 102 (1997).

4.0 Assigning Monetary Values

As we have seen in the previous sections of this report, most of the non-air benefits of renewable power systems relate to avoided negative impacts of conventional power systems. By assigning a monetary value to these benefits, it may be possible to measure the value of the change in ecosystem components resulting from the use of different technologies to assess the relative benefits of one form of power generation compared to another. In this way, it may be possible to carry out an assessment of various power generation options on equal (monetary) terms.

Historically, the estimation of the monetary benefits of renewable energy has mostly related to avoided air emissions (see section 3.2 above). It may be possible to apply these valuation methods to the non-air benefits presented by renewable power when compared to conventional power sources. Natural capital and ecological function assessments are also being used to evaluate different land uses and drawing on these methods could be a useful way to level the playing fields for renewable energy.

The value of non-air ecological benefits has been dealt with extensively in the ecological and environmental economics literature. Much of the primary research on monetary valuation has focused on examining the increased value that consumers put on renewable energy[45] but the research does not measure the value of the non-air benefits that these technologies provide relative to conventional (fossil fuel based) power systems.

More recent research has been carried out using the ecological footprint method to determine the entire suite of ecological benefits provided by many products including renewable energy.[46] This research presents considerable opportunity to go further to assign monetary values to the non-air benefits provided by renewable energy using benefits transfer methods.

Several examples of valuation of air emission externalities exist (as reviewed in section 3.2). One study provides valuations of agricultural, timber, water resources, noise and visual intrusion of a number of conventional and renewable sources, but in no case were these impacts estimated for all sources.[47] As noted in section 3.4, this study concluded that, although external costs do not accurately reflect the traditional value system of individual decision makers as reflected in multi-criteria assessment, they give suitable price signals and thus help in eliminating distortions of the current energy market.

The types of valuation and some of the most relevant methods for conducting valuation are described in this section of the report.

4.1 Ecosystem Goods and Services Valuation

Ecosystem goods and services valuation is the process of assigning a monetary value to ecological components and/or the services those components provide. Valuation provides a common basis upon which to compare the social, economic and environmental implications of policy decisions, allowing policy makers to fully account for the benefits that the natural environment provides to society. Placing a value on

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[45] Ryan Wiser. "Using contingent valuation to explore willingness to pay for renewable energy: A comparison of collective and voluntary payment vehicles." *Ecological Economics* vol. 62 (2007): 419-432.

[46] Huijbregts, Mark, Hellweg, Stefanie, Frischknecht, Hungerbuhler, Konrad, and Hendriks, J.A. "Ecological footprint accounting in the life cycle assessment of products" *Ecological Economics* (In Press) 2007.

[47] Mirasgedis, Sebastianos and Dzidonu Diakoulaki. "Multicriteria Analysis vs. Externalities Assessment for the Comparative Evaluation of Electricity Generation Systems," *European Journal of Operational Research* 102 (1997).

ecosystem goods and services requires the use of tailored methods that determine the value of a good or service.

While a degree of uncertainty and subjectivity exists when undertaking ecosystem goods and services valuation, established methodologies (as will be discussed below) serve to limit such concerns. Ecosystem goods and services valuation is based on the working assumption that humans depend on the services that ecosystems provide. Without adequately addressing the value of ecosystem components in a market-based economic system, natural resource use and economic growth tend to factor these goods in at no cost, thereby demanding more and more. But in reality an ecosystem has a value equivalent to the sum of its ecosystem functions and all the benefits to humans from the ecosystems existence. Just as a value can be placed on the annual allowable cut from a timber stand, a value can be placed on other goods and services, water filtration, carbon sequestration or nutrient cycling, that ecosystems provide.

Valuation can be done at various scales; it can be done for a particular ecosystem component (such as a wetland), at a landscape or watershed level, or for a defined region (province, country, continent, etc.).

There are a number of challenges associated with pursuing ecosystem goods and services valuation:

- The availability of appropriate and adequate data.
- Providing a clear link between science and economic benefits.
- Some valuation techniques can be prone to bias.
- Lack of trained professionals.
- Interdisciplinary cooperation.
- Public understanding/acceptance of the importance of valuing ecological goods and services.

4.2 Valuation Methodologies

Generally, ecosystems consist of four types of values:

- Direct use value – the value derived from the direct use of the ecosystem or resource, such as the value of a caribou as a food source.
- Indirect use value - the value derived from the indirect use of the ecosystem or resource, such as the value of a wetland in flood control.
- Option value – the value derived from preserving a resource or ecosystem today for the option of using it in the future, e.g. preserving a tree today so that it may be used in the future.
- Non-use value – also referred to as the inherent value, consists of three types of values: a) the value others may derive from a resource or ecosystem, b) the value future generations may derive from a resource or ecosystem, and c) the value derived from knowing the resource or ecosystem exists.

The values described above can be determined in three ways:

- Revealed Preference Method – Using market prices to measure the benefit or cost to individuals for a particular course of action by observing people's behaviour in defined markets. Examples of revealed preference methods include: production function, replacement cost, travel cost and hedonic pricing.
- Stated Preference Method – Using surveys to determine people's preferences (measured in willingness to pay or willingness to accept) for a hypothetical course of action. Examples of stated preference methods include: contingent valuation and choice modeling.

- Benefits Transfer Method – Using valuation information from other jurisdictions with similar characteristics.

For two of the three methods presented above, revealed preference and stated preference, a number of specific methodologies have been developed that address specific ecosystem functions and processes. Table 3 describes the methodologies for determining values for environmental goods and services and identifies the approach, applications, data requirements and limitations associated with each.

Table 3: Overview of Valuation Methods[48]

Methodology	Approach	Application	Data Requirements	Limitations
Revealed Preference Methods				
Production Function	Trace the impact of a change in ecosystem services on produced goods	Any measurement of impacts on produced goods	Change in service impact on production, net value of produced goods	-Data that links the change in service with the change in production is often lacking -Market imperfections (subsidies, lack of transparency) distort the market price
Cost of Human Capital	Trace the impact of a change in ecosystem services on morbidity or mortality	Any impacts that affects health	Change in service impact on human health, cost of illness or value of life	-Linking environmental condition to human health is difficult and often lacking. Value of life is not estimated easily
Replacement Cost	Estimate the cost of replacing the lost good or service	Any loss of goods or services	Extent of loss of goods or services. Cost of replacing them (e.g. cost of replacing forests)	-Tends to over-estimate actual value, should be used with extreme caution.
Travel Cost	Derive a demand curve from data on actual travel costs	Recreation	Survey to collect monetary and time costs of traveling to a destination	-Limited to recreational benefits; hard to use when trips are to multiple destinations
Hedonic Pricing	Extract the effect of environmental or situational factors on the price of goods that include those factors	Air quality, scenic beauty, cultural benefits	Prices and characteristics of goods (e.g. housing values)	-Requires vast quantities of data -Very sensitive to specification
Stated Preference Methods				
Contingent Valuation	Ask respondents their willingness to pay for a specified service	Any service	Scenarios questioning peoples willingness to pay for goods and services	-Many potential sources of bias in responses but guidelines exist for reliable application
Choice Modeling	Ask respondents to choose their preferred option from a set of alternatives	Any service	Survey of respondents	-Similar to that of contingent valuation -Analysis of the data is complex
Other Methods				
Benefits transfer	Use results obtained elsewhere	Any service for which a comparison exists	Valuation exercises at another, similar site	Can be very inaccurate as many factors vary even when the context seems similar

[48] Modified from: Pagiola, Stefano, "How much is an ecosystem worth?: Assessing the economic value of conservation." World Bank, 2004. See www.biodiversityeconomics.org/document.rm?id=710 Accessed January 2007.

A broad body of literature exists dealing with environmental valuation.[49] Some studies provide further guidance on methods for the monetary valuation of the environmental impacts of electricity, while serving as case studies of valuation methods. Kammen and Pacca (2004) provide a survey of methods to compute electricity costs, including premiums associated with environmental risks or impacts.[50]

Complex considerations exist for many valuation approaches. An example of one of these complexities is that society's preference may change over time, rendering past revealed preferences inadequate for valuation purposes using a revealed preference approach. A critical survey of environmental impacts valuation for electricity generation was carried out in 2002 by Sundqvist and Söderholm. This survey notes that "[t]he usefulness of previous economic valuation efforts for policy purposes is … complicated by the facts that according to the welfare economics literature, valuation builds on: (a) relatively restrictive behavioral assumptions: and (b) the idea that the ethical principle guiding social choice is economic efficiency."[51] Their findings also indicate that [s]ince people are likely to express public rather than private (i.e., utility maximizing) preferences towards some external impacts, the social choice between different power sources must increasingly be made within the realms of public discourse where additional ethical principles may play a role."[52] These relatively intangible elements of valuation can represent "moving targets" that are difficult to capture.

Differing values can further complicate such valuation approaches: "the view that economic efficiency is the ultimate goal of policy is not likely to be shared by all lay people and politicians. This means that, in contrast to many economists, they are likely to be more indulged to promote […] a much broader definition of externalities than that available in the literature."[53]

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[49] For a more detailed discussion of monetary valuation methods of environmental services and impacts, see Garrod, Guy and Ken Willis, Economic Valuation of the Environment: Methods and Case Studies. Cheltenham: Edward Elgar (1999).
[50] Kammen, Daniel and Sergio Pacca. "Assessing the Costs of Electricity," *Annual Review of Environment and Resources 29*: 301-344 (2004).
[51] Sundqvist, Thomas and Patrik Söderholm. "Valuing the Environmental Impacts of Electricity Generation." *Journal of Energy Literature 8*, no. 2 (2002).
[52] Ibid
[53] Ibid.

5.0 A Guide to Estimating Benefits

This section provides a step-by-step guide for renewable power source project developers to identify and estimate the non-air benefits of their project. It provides the user with the option of using the information contained in section 2 of this report, or to use a more rigorous multi-criteria assessment approach described in section 3. The steps are as follows:

1. Make sure the renewable power project meets sustainability criteria for the technology used. Use Table 2 in Section 2 to estimate any negative impacts if it cannot meet all criteria.
2. Define the size and type of all conventional power sources that the project could replace or displace.
3. Using Table 1 in Section 2, estimate the impacts of these equivalent conventional power sources to obtain an estimate of individual land use, water consumption, water quality, solid waste/ground contamination, and biodiversity benefits of the project.
4. If data and time are available, use a multi-criteria approach described in Section 3 to make a more rigorous comparison with conventional power sources, including ranking among non-air benefits.
5. If a monetary value of the benefits is possible, use one of the methods described in Section 4 to make an estimate.

Step1: Ensure the project meets sustainability criteria

All projects: Eco-Logo universal criteria. For electric power to be renewable it must:

- Be generated in such a manner that all steps of the generation process meet the requirements established by applicable laws and regulations;
- Be accompanied by evidence that appropriate consultation with communities and stakeholders has occurred, and when applicable reasonable mitigation of negative impacts has been addressed;
- Be accompanied by evidence that the project will not result in land conflict, biodiversity loss, or degradation of the heritage, cultural, recreational or touristic values; and
- Be generated in a manner that does not adversely impact species designated as endangered or threatened.

Criteria for each type:

Solar PV (Eco-Logo):

- Be generated in such a manner that adequate arrangements have been made to ensure proper disposal or recycling of all solid waste, including final disposal of equipment and machinery used.

Solar Thermal Electric: None available

Wind (Eco-Logo):

- Not be detrimental to indigenous or migratory avian species;
- Not be located in an area that is protected for endangered or threatened avian species;
- Not cause excessive soil erosion; and

- Have replanted uprooted vegetation and replaced excavated soil after construction or demolition.

Hydro - with storage (International Hydropower Association Sustainability Guidelines, Low Impact Hydropower Institute[54] / Green-e)

Mitigation strategies must have been taken with respect to:

- Water quality
- Sediment transport and erosion
- Downstream hydrology and environmental flows (including seasonal fluctuation)
- Watershed protection
- Rare and endangered species
- Passage of fish species
- Flora and fauna pest species within reservoir
- Health issues
- Construction activities
- Environmental management systems

Hydro - run of river (Eco-Logo, Green-e):

- Not operate under authorization that allow the harmful alteration or disruption of fish habitat, unless the alteration does not affect the limiting factor controlling productive capacity, and loss of the affected habitat is compensated by the creation of similar habitat;
- Operations are coordinated with other water-control facilities to mitigate impacts; Operate such that:
    - Reduced water flows in the bypassed reaches are not detrimental to indigenous inhabiting species,
    - In-stream flows downstream are adequate to support indigenous inhabiting species, and
    - Water quality is comparable to unaltered bodies within the local watershed, including ensuring water temperature changes are not detrimental to indigenous inhabiting species; and
- Provide measures to minimize fish mortality that would result from impingement and entrainment, and ensure fish passage exists where man-made structures are placed where no natural barriers exist.
- Green-e suggests run-of-river facilities have nameplate capacities of 5 MW or less.

Biomass: (Eco-Logo, National Wildlife Federation (US), Brazilian Forum of NGOs and Social Movements (FBOMS), Energy Transition Task Force of the Netherlands, Green-e)

- Avoid local competition for land, raw materials, water and labour associated with the production of food, building materials, energy supply and medicines.
- Maintain soil structure and fertility through conservation tillage, crop rotation, terraces, cover crops, buffer strips, grassed waterways, and timed tillage, leaving adequate crop residues.

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[54] Low Impact Hydropower Institute. "Low Impact Hydropower Certification Criteria: Summary of Goals and Standards." Available at <http://www.lowimpacthydro.org/documents/criteria_summary.pdf>. Accessed May 2008.

- Protect biological diversity, both terrestrial and aquatic, and maintain wildlife abundance and distribution.
- Maximize use of crop diversity, agro-forestry; discourage monocultures, and use of persistent chemicals.
- No destruction of primary forests, native prairie/grasslands, or other areas containing High Conservation Values for energy crops.
- Use native species/varieties/perennials where appropriate; avoid invasive species and GMO varieties.
- Use only wood-wastes and/or agricultural wastes that have been sourced from operations that have implemented a sound environmental management system and are adhering to sound environmental management practices,
- Use only dedicated energy crops that have been sourced from operations that have implemented a sound environmental management system and are adhering to sound environmental management practices.
- Ensure the rate of harvest does not exceed levels that can be sustained, and not use wastes from species that are listed in the CITES Appendices.
- Municipal solid waste may be eligible if first converted to a clean-burning fuel. Technology for fuel conversion should be a non-combustion process, should produce no hazardous wastes or discharges of water, and should remove all recyclable materials from the waste stream.

Biogas: No specific criteria available for non-air benefits

Wave/Tidal: None available

Geothermal: None available

If the project meets these criteria, it may be assumed that there are no significant negative impacts associated with this project. If the project cannot meet these criteria, then the impacts listed in Table 2 must be taken into account in step 3.

Step 2: Define conventional alternatives to meet the same load

The benefits of the renewable energy project will depend on the avoided non-air impacts of conventional power projects that would meet the same power requirements in the same location.

Most typical renewable energy power plants are smaller than conventional power plants and make the grid more decentralized. However, a large number of these plants controlled by new smart grid control systems and incorporating power storage systems such as pumped storage and advanced batteries, in future will be able to displace larger conventional plants. Conventional alternatives to renewable power systems should therefore include all possible options for the location. Use appropriate capacity factors and peak effectiveness factors to determine the equivalent size of conventional project, and then scale the impacts/benefits from a typical plant size.

For example, for a 100 MW wind project with a capacity factor of 36% would be equivalent to 50 MW of nuclear capacity with a factor of 72%[55], and 43 MW of coal capacity with a factor of 85%.

[55] Typical for nuclear power plants in Ontario if unscheduled outages and repairs are taken into account.

Step 3: Use Tables 1 and 2 to estimate benefits of renewable energy project

Table 1 can be used to identify and where possible estimate the size of the conventional plant impacts avoided by the renewable energy power plant for each of the five impact categories. Scaled to the size of the renewable power plant they become the non-air benefits of the renewable energy project.

If the renewable energy project could not meet the strict criteria set for that type of project, then any negative impacts identified in Table 2 will need to be set against these benefits.

Step 4: More rigorous estimate of non-air benefits using multi-criteria assessment

Based on the above assessment of methodologies that can be used to compare conventional and renewable power sources in Section 3, it is recommended that a multi-criteria assessment approach be used for a more rigorous estimate of non-air benefits and to rank these benefits. The multi-attribute approach is more suitable when fewer quantitative estimates are available and the benefits (or impacts) vary greatly as they do with non-air benefits.

Multi-criteria assessment also provides the opportunity to formally involve a wide range of stakeholders, and also allow for the inclusion of other comparative considerations, including social, economic and emissions-related impacts of different power sources.

Step 5: Value benefits

If enough benefits have been quantified then monetary valuation of these benefits will provide additional inputs for the multi-criteria assessment – allowing participants to make better judgments as to the importance of each benefit. It would also allow comparison of monetary benefits using contingent evaluation approaches described in Section 4 above.

6.0 Conclusions and Recommendations

6.1 Conclusions

There are very few quantitative measures of non-air environmental impacts available for either conventional or renewable power sources. Land use area per MW is the exception, but the large differences in the types of land impact result in limited utility for many of these measures.

Many of the non-air impacts of conventional and renewable energy power sources are unique to a particular power source, making it difficult to compare power sources and identify benefits. For example:

- The significant visual impacts of wind power plants
- The ability to install solar PV systems on existing structures, using no new land area
- The significant radiation and long term waste impacts of nuclear power

With the exception of hydro, there are few examples of large-scale renewable power plants that are equivalent in size to a typical nuclear or coal power plant that can be used to quantify environmental benefits. Both renewable and conventional power technologies are evolving rapidly (e.g. wind/storage and clean coal) making benefits assessment a moving target.

In general, if renewable energy power sources meet the sustainability guidelines developed and applied by internationally recognized stakeholder organizations, it may be assumed that the environmental impacts of these power projects are small. The benefits of these power projects are therefore the avoided impacts of the conventional power systems that they displace.

The most significant benefits of renewable power sources are the avoided negative impacts on water quality, reduced solid waste, and avoided negative impacts on biodiversity from coal and nuclear power sources.

Because of the lack of quantitative data and the significant differences in the type of non-air impacts of power sources, the only effective way to rigorously estimate the benefits of a renewable power project is to use multi-criteria assessment, where a wide variety of subjective participant weightings are rigorously compared and analyzed.

Monetary estimations of non-air environmental benefits of renewable power sources are currently limited to measuring the abated costs of alternative, non-renewable, energy systems. In this regard the most promising areas appear to be the monetary valuation of avoided ecosystem loss. What is evident is that people do put a premium on renewable energy.[56]

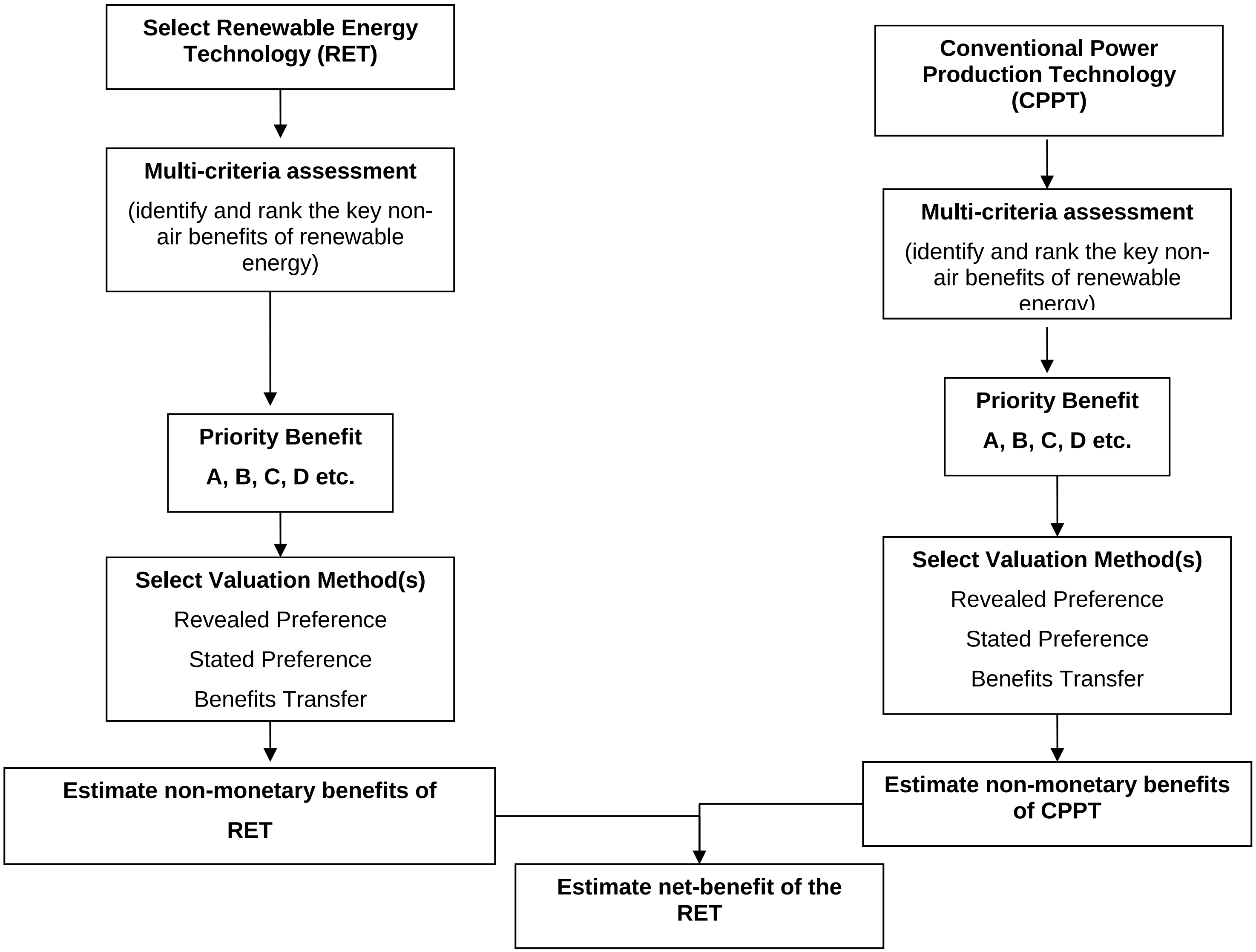
6.2 Recommendations

There is a considerable amount of research and analysis required to assess the full value afforded to people and ecosystems by the transition from conventional power systems to renewable energy systems. In conducting the research for this report, a number of key areas for additional work were evident. These include:

[56] Ryan Wiser. “Using contingent valuation to explore willingness to pay for renewable energy: A comparison of collective and voluntary payment vehicles.” *Ecological Economics* vol. 62 (2007): 419-432.

- Further research to identify quantitative measures of non-air environmental benefits in areas where real comparisons can be made among power sources for benefits related to water consumption and land use.
- Development of sustainability criteria for wave, tidal and biogas power systems.
- A pilot application of multi-criteria assessment of all environmental impacts (including non-air impacts) for a number of conventional and renewable power sources that could meet the same new power demand.
- Development of a framework for renewable energy project proponents to follow to assess the non-air environmental benefits of their system.
- Development a framework for policy makers to conduct valuations of the non-air benefits associated with renewable energy versus that of conventional energy systems and how to effectively monetize these benefits. See suggested framework below.
- Apply these frameworks to some actual projects where sufficient data on the renewable power system and conventional alternatives can be obtained.

Framework to conduct valuations of the non-air benefits associated with renewable versus that of traditional energy systems and how to effectively monetize these benefits.



Appendix 1: Estimating Impacts of Conventional Technologies

Note: italics denote verbatim reproduction of relevant sections from source material.

Coal

Environmental impacts associated with the use of coal as an energy source are extensive and include ecosystem degradation, modification of surface and groundwater flow patterns, waste and effluent production, and air emissions. Impacts depend on a number of factors including the coal type, location of the coal seam, methods employed in extraction and processing, and combustion technology.[57]

Mining:

Strip mining is used to extract more than 90% of coal in Canada. Direct land impacts on average extend over 335 ha per mine, resulting in habitat destruction and fragmentation. Disturbance of surface water flow patterns and downstream sedimentation are not uncommon. Removal of overburden and mine dewatering can greatly affect the quantity and distribution of groundwater: dewatering has on some occasions destroyed viable water supplies for rural residences through aquifer drainage. [58]

The US Geological Survey has calculated that the **sediment** yield from strip-mined portions of a watershed can be 10–1500 times the amount from undisturbed land. Large quantities of solid waste are produced during the extraction and cleaning (washing) stages. Approximately 19% of all raw mined coal in Canada becomes waste material and is discharged as tailings.[59] Open pit mining permanently changes large land areas. Between 1930 and 2000, coal mining disturbed approximately 2.4 million hectares of land in the U.S., much of which was once forest.[60].

In addition to old, abandoned mines, coal mines supplying electric power plants currently disturb about 680,000 hectares - The U. S. Department of the Interior's Office of Surface Mining first collated voluntary reports by states and tribes of land disturbed by coal mining in 1998.[61]

According to the most recent EIA data, those reporting entities accounted for only 60% of total U. S. coal production. Disturbed area for non-reporting states calculated roughly from their 1997 coal production as a fraction of U. S. total production. Result multiplied by 85%, the portion of U. S. coal production that supplies power plants.,[62]

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[57] From Cuddihy, John et al. “Energy use in Canada: environmental impacts and opportunities in relationship to infrastructure systems,” Canadian Journal of Civil Engineering 32 (2005). <http://pubs.nrc-cnrc.gc.ca/rp/rppdf/l04-100.pdf> Accessed December 2007.

[58] Ripley, Earle and Robert Redmann. Environmental Effects of Mining. CRC, Boca Raton, FL (1996).

[59] Ripley, Earle and Robert Redmann. Op cit

[60] Jeff Skousen, Paul Ziemkiewicz, and Christina Venable, "Evaluation of Tree Growth on Surface Mined Lands in Southern West Virginia". In Serchuk, Adam. “The Environmental Imperative for Renewable Energy: an Update,” Renewable Energy Policy Project Special Earth Day Report, Washington, DC (2000). Available online at <www.crest.org/repp_pubs/articles/envImp/04impacts.htm> and <www.repp.org/repp_pubs/articles/envImp/earthday.exec.summ.pdf>.

[61] *OSM, 1998 Annual Report, at <www.osmre.gov/ anrep98 htm>.*

[62] *Data from <www.eia.doe.gov/cneaf/coal/ statepro/tables>, <www.eia. doe.gov/cneaf/coal/quarterly/ html/t3p01p1.html> and <www.eia.doe.gov/cneaf/coal/quarterly/html/ t37p01p1 html>,*in in Serchuk, Adam. “The

The amount of waste generated is highly dependent on the coal type, with bituminous coal generating the most significant quantities. The trace metal composition of coal is highly dependent on grade and region.[63] *Metals and other trace elements are a concern for wastewater discharges, seepage from open pits, stockpiles, and waste rock dumps, and dust emissions. Discharges and seepage may also contain high levels of nitrogen, primarily from blasting agents (ammonium nitrate) and fuel oil. Wastewater characteristics vary widely in terms of* **chemical** *composition, pH, solute composition, and total suspended solids (TSS) levels; in general, treatment is required prior to discharge. Methane is often trapped in coal seams and upon mining is emitted to the* **atmosphere**.[64]

A systemic understanding of pollutant emissions and energy utilization is necessary when considering processes for emissions reduction and (or) increased combustion efficiency. Depending on the treatment process, transferring sulphur from the marketable coal to the solid waste stream can transform a potential atmospheric emission problem into one of acid drainage.

Power Generation:

Thermal plants using coal generate significant quantities of solid waste both in terms of sludge from flue gas desulphurization and from fly and bottom ash. Depending on the quality and type of fuel, solid waste may contain toxic, hazardous, and (or) radioactive materials. Depending on the composition of coal used, disposal of waste ash alone can require more than 1 acre per MW of installed capacity.[65]

The direct physical impacts of generation, not including fuel mining, have been estimated to be approximately 19 acres / MW capacity.[66]

Natural Gas

Water emissions attributed to production primarily result from the discharge of produced water (fluid injected during drilling). The toxicity of these drilling fluids is highly variable, depending on their formulation. Water is used as the base fluid for roughly 85% of drilling operations internationally, and the remaining 15% predominantly use oil). Produced water contains various contaminants including trace elements and metals from formations through which the water passed during drilling as well as additives and lubricants necessary for proper operation.[67] *It is typically treated prior to discharge, although historically this was not the case.*[68] *Spills make up only a small component of aquatic discharges.*[69]

Environmental Imperative for Renewable Energy: an Update," Renewable Energy Policy Project Special Earth Day Report, Washington, DC (2000). Available online at <www.crest.org/repp_pubs/articles/envImp/04impacts.htm>..

[63] Ripley, Earle and Robert Redmann. Environmental Effects of Mining. CRC, Boca Raton, FL (1996).

[64] Cuddihy, John et al. "Energy use in Canada: environmental impacts and opportunities in relationship to infrastructure systems," *Canadian Journal of Civil Engineering 32* (2005). <http://pubs.nrc-cnrc.gc.ca/rp/rppdf/l04-100.pdf> Accessed December 2007.

[65] World Bank. "India: Strengthening Institutions for Sustainable Growth – Country Environmental Analysis", (2005). <siteresources.worldbank.org/INDIAEXTN/Resources/295583-1176163782791/ch2.pdf> Accessed December 2007.

[66] <www1.eere.energy.gov/geothermal/printable_versions/geopower_landuse.html>

[67] Cuddihy, John et al. "Energy use in Canada: environmental impacts and opportunities in relationship to infrastructure systems," *Canadian Journal of Civil Engineering 32* (2005). <http://pubs.nrc-cnrc.gc.ca/rp/rppdf/l04-100.pdf> Accessed December 2007.

[68] Ahnell, A. and O'Leary, H. "Drilling and production discharges in the marine environment," *In* Environmental technology in the oil industry. *Edited by* S.T. Orszulik. Blackie Academic & Professional, London (1997) *in* Cuddihy, John et al. "Energy use in Canada: environmental impacts and opportunities in relationship to infrastructure systems," *Canadian Journal of Civil Engineering 32* (2005). <http://pubs.nrc-cnrc.gc.ca/rp/rppdf/l04-100.pdf> Accessed December 2007.

Statistical information tends to focus on the discharge- related environmental impacts of the industry rather than on ecological impacts including habitat destruction and fragmentation; however, these must be recognized as major concerns associated with petroleum and natural gas developments in both terrestrial and aquatic environments.[70]

Gas-fired plants produce almost no solid waste.[71]

Nuclear

Land Use: The Sustainable Development Commission estimates that the land-take for a 1,000 MW nuclear power plant is between 100 and 400 ha.[72]

Other environmental impacts attributable to nuclear power generation can result from radiation, accidents, atmospheric emissions and water intake during operation, and the disposal of processed fuel. The following examples are from a recent review of the Canadian nuclear fuel and power cycle by the Pembina Institute. [73]

Uranium mining and milling:

- An estimated 575,000 tonnes of tailings per year, of which 90–100,000 tonnes can be attributed to uranium production for domestic energy purposes. Uranium mill tailings are acidic or potentially acid generating, and contain a range of long-lived radionuclides, heavy metals and other contaminants. Tailings generation would increase proportionally with the use of lower grade uranium ores, as larger amounts of ore would have to be processed to produce the same amount of uranium concentrate.
- Up to 18 million tonnes of waste rock, which may also contain radionuclides, heavy metals, and be acid generating. Of this total up to 2.9 million tonnes can be attributed to uranium mining for domestic energy purposes.
- It is estimated that there are more than 213 million tonnes of uranium mine tailings in storage facilities in Canada, and 109 million tonnes of waste rock.

Refining and conversion operations:

- It is estimated that nearly 1,000 tonnes of solid wastes and 9,000 m^3 of liquid wastes are produced per year as a result of uranium refining, conversion and fuel production for domestic energy generation purposes. Information on the precise character and fate of these wastes could not be obtained.

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[69] Liu, Paul. Introduction to energy and the environment. Op cit

[70] Cuddihy, John et al. “Energy use in Canada: environmental impacts and opportunities in relationship to infrastructure systems,” *op cit*

[71] Fay, James and Dan Golomb. Energy and the environment. Oxford University Press, New York (2002) *in* Cuddihy, John et al. “Energy use in Canada: environmental impacts and opportunities in relationship to infrastructure systems,” *Canadian Journal of Civil Engineering 32* (2005). <http://pubs.nrc-cnrc.gc.ca/rp/rppdf/l04-100.pdf> Accessed December 2007.

[72] Sustainable Development Commission. “The Role of Nuclear Power in a Low Carbon Economy: Paper 3 – Landscape, Environment and Community Impacts of Nuclear Power,” (2006). Available at <www.sd-commission.org.uk/publications/downloads/Nuclear-paper3-landscapeEnvironmentCommunity.pdf. Accessed November 2005>.

[73] Nuclear Power in Canada: An Examination of Risks, Impacts and Sustainability. The Pembina Institute (2006). www.pembina.org/pub/1346

Power Plant operation:

- Approximately 85,000 waste fuel bundles are generated by Canadian nuclear reactors each year. As of 2003, 1.7 million bundles were in storage at reactor sites. It is estimated that these wastes will have to be secured for approximately one million years for safety, environmental and security reasons.
- Approximately 6,000 tonnes of lower level radioactive wastes are generated each year in Ontario as a result of power plant operations, maintenance, and refurbishment.
- Power plant maintenance and refurbishment also result in the generation of substantial amounts of additional hazardous wastes, including heavy metals and asbestos.
- Very large amounts of low-, intermediate- and high-level radioactive wastes will be produced as a result of the eventual decommissioning of refining, conversion and fabrication facilities and power plants. The costs of decommissioning Ontario's existing reactors have been estimated at $7.474 billion (present value $6.263 billion)

Water consumption and discharge concerns are similar to those associated with thermal power plants. Impingement and entrainment of fish and other aquatic biota may occur as a result of intakes, and thermal pollution resulting from discharge of condensed steam may adversely affect aquatic ecosystems.[74]

The disposal of used fuel is often considered to be the most significant potential environmental impact associated with the nuclear power generation industry. Difficulties with long-term management practices such as deep geological disposal include risks associated with possible corrosion of fuel containers, dissolution of uranium, and release and migration of radionuclides.[75] *Uncertainties are primarily related to site characteristics including water flow rate, direction and chemical composition at depth, and rock type and integrity at depth. Although environmental impacts due to spent fuel disposal have not been realized, there is significant perceived risk, and long-term impacts are difficult to predict.*[76]

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[74] From Cuddihy, John et al. "Energy use in Canada: environmental impacts and opportunities in relationship to infrastructure systems," *Canadian Journal of Civil Engineering 32* (2005). <http://pubs.nrc-cnrc.gc.ca/rp/rppdf/l04-100.pdf> Accessed December 2007.

[75] Wiles, Donald. The Chemistry of Nuclear Fuel Waste Disposal. Polytechnic International Press, Montreal (2002).

[76] From Cuddihy, John et al. op cit

Thermal Generation (applicable to all once-through thermal generators)

Water consumption and thermal pollution are closely related. Statistics Canada demonstrates that nuclear and fossil fuel power generation are together responsible for roughly 64% of all water intakes nationally. The water is used to make steam to drive the turbines, following which it is condensed, with the waste heat (representing roughly one third of the fuel energy) being transferred to a cold reservoir. According to OPG, almost all the water used by both its fossil fuel and nuclear stations is used in single-pass cooling procedures. As such, thermal pollution results from the reintroduction of this water to its body of origin.

Net water consumption, the water that was not returned to its body of origin, represented approximately 10% of all water consumption nationally in 1996. Lastly, in some cases, large-scale water intakes may result in harm to fish and other aquatic life through impingement and entrainment.[77]

Negative impacts on water quality result from pollutants and significant changes in water temperature. Cooling systems for large thermal electric plants like coal, combined cycle natural gas, and nuclear can have significant adverse impacts on local water temperature. Some plants are responsible for the death of more than one million fish per operating year largely due to water temperature increases.[78]

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[77] From Cuddihy, John et al. "Energy use in Canada: environmental impacts and opportunities in relationship to infrastructure systems," *Canadian Journal of Civil Engineering 32* (2005). <http://pubs.nrc-cnrc.gc.ca/rp/rppdf/l04-100.pdf> Accessed December 2007.

[78] Serchuk, Adam. "The Environmental Imperative for Renewable Energy: an Update," Renewable Energy Policy Project Special Earth Day Report, Washington, DC (2000). Available online at <www.crest.org/repp_pubs/articles/envImp/04impacts.htm> and <www.repp.org/repp_pubs/articles/envImp/earthday.exec.summ.pdf>

Appendix 2: Estimating Impacts of Renewable Technologies

Note: italics denote verbatim reproduction of relevant sections in source material.

Hydro with Dam and Storage

The development of major hydroelectric power generation capacity is generally associated with a short period of more intensive impact (construction) followed by various potential ongoing effects. Construction impacts are primarily associated with the flooding of significant tracts of land and the production of greenhouse gases, and continuing effects include the impingement and entrainment of fish in turbines and the disturbance of fish migration paths. In addition, the construction of transmission lines and the clearing of the right-of-way can result in significant habitat degradation and (or) fragmentation.

The environmental impacts associated with the extensive flooding required for development of reservoirs and resulting from the redirection of rivers are among the most significant attributable to large-scale hydroelectric power generating schemes. Local wildlife is displaced, migration patterns are affected, and habitat is destroyed. In addition to the physical alteration of downstream flows, increased levels of evaporation are also experienced due to the creation of reservoirs. Ecosystems are fragmented, downstream water quality is altered, and increased sedimentation often occurs. Upstream water quality (in the reservoir) may also be compromised. In the case of the La Grande hydroelectric development in Quebec, for example, bacterial activity in flooded soil and vegetation resulted in the formation of methyl mercury, a biologically accumulative and toxic form of mercury. [79]

The International Hydropower Association, an association of organizations and individuals involved in hydropower in more than 80 countries, has developed a set of sustainability guidelines[80] *to ensure the sustainable development of hydropower resources. The IHA has identified the following potential impacts of hydro power reproduced from the IHA Guidelines.*

Water quality:

Changes in water quality are likely to occur within and downstream of the development as a result of impoundment. The residence time of water within a reservoir is a major influence on the scale of these changes, along with bathymetry, climate and catchment activities. Major issues include reduced oxygenation, temperature, stratification potential, pollutant inflow, propensity for disease proliferation, nutrient capture, algal bloom potential, and the release of toxicants from inundated sediments.

Sediment transport and erosion:

The creation of a reservoir changes the hydraulic and sediment transport characteristics of the river, causing increased potential sedimentation within the storage and depriving the river downstream of

[79] From Cuddihy, John et al. "Energy use in Canada: environmental impacts and opportunities in relationship to infrastructure systems," *Canadian Journal of Civil Engineering 32* (2005). <http://pubs.nrc-cnrc.gc.ca/rp/rppdf/l04-100.pdf> Accessed December 2007.

[80] International Hydropower Association Sustainability Guidelines (source: http://www.hydropower.org/downloads/IHA_Guidelines_NOV%20%2703Int.pdf).

material. Sedimentation is an important sustainability issue for some reservoirs and may reduce the long-term viability of developments. Reduction in the sediment load to the river downstream can change geomorphic processes (e.g. erosion and river form modification).

Downstream hydrology and environmental flows:

Changes to downstream hydrology impact on river hydraulics, in-stream and streamside habitat, and can affect local biodiversity.

Rare and endangered species:

The loss of rare and threatened species may be a significant issue arising from dam construction. This can be caused by the loss or changes to habitat during construction disturbance, or from reservoir creation, altered downstream flow patterns, or the mixing of aquatic faunas in inter-basin water transfers. Hydropower developments modify existing terrestrial and aquatic habitats.

Passage of fish species:

Many fish species require passage along the length of rivers during at least short periods of their life-cycle. In many places the migration of fish is an annual event and dams and other in-stream structures constitute major barriers to their movement. In some cases the long-term sustainability of fish populations depend on this migration and in developing countries local economies can be heavily reliant on this as a source of income.

Pest species within the reservoir (flora & fauna):

In some regions a significant long-term issue with reservoirs, irrespective of their use, is the introduction of exotic or native pest species. The change in environment caused by storage creation often results in advantageous colonization by species that are suited to the new conditions. These are likely to result in additional biological impacts. In some instances, proliferation may interfere with power generation (e.g. clogging of intake structures) or downstream water use through changes in the quality of discharge water (e.g. algal bloom toxins, deoxygenated water).

Health issues:

The changes brought about by hydropower developments have the capacity to affect human health. Issues relating to the transmission of disease, human health risks associated with flow regulation downstream and the consumption of contaminated food sources (e.g., raised mercury levels in fish) need to be considered.

Run of River Hydro

Hydro-electric facilities that do not include storage but divert a portion of the river flow for power production can still have an environmental impact, albeit usually less than a dammed river. EcoLogo, one of the best-recognized environmental labelling programs in North America, provides criteria and standards for certifying products in over 100 categories, includes criteria for low-impact renewable electricity. EcoLogo Guidelines for run of river hydro list the following potential impacts[81]:

- Harmful alteration or disruption of fish habitat
- Reduced water flows in the bypassed reaches are detrimental to indigenous inhabiting species,
- In-stream flows downstream are not adequate to support indigenous inhabiting species, and
- Water temperature changes are detrimental to indigenous inhabiting species
- Fish mortality resulting from impingement and entrainment, and barriers to fish passage

Solar Photovoltaic Power Systems

No land resources are required for operation of residential solar photovoltaic systems, which are installed on existing structures.

Land utilization for utility scale "greenfield" solar PV systems is estimated to be about 2.5 Ha/MW.[82] The California Energy Commission estimates that solar photovoltaic installations require approximately 9 acres (3.6 Ha) per MW of capacity.[83]

UTILITY-SCALE FLAT-PLATE THIN FILM PHOTOVOLTAICS

5.0 Land, Water, and Critical Materials Requirements

Table 4. Resource requirements.

Indicator Name	Units	Base Year 1997	2000	2005	2010	2020	2030
Land	ha/MW	5	4	3	2.5	2.5	2.5
	ha	0.08	9.6	24	40	40	40
Critical elements (e.g., In, Se, Ga, Te)	MT/GW_p	NA	50	30	20	10	3
Water	m^3	nil	nil	nil	nil	nil	nil

Land area needs are based on calculating the array area required to produce the desired output, amount of energy per square meter of array and then multiplying this area by a factor of about 2.5 to account for packing the arrays without shadowing. At 10% system efficiency, a PV system produces about 100 W/m^2 of array. Including the packing factor, this is 40 W/m^2 of land area. A MW would thus require 25,000 m^2 of land, or about 0.025 km^2. In the early years, we expect system efficiency to be below 10% (accounting for the larger land requirements), but by 2010, system efficiency of over 10% is assumed (accounting for the lower land-use numbers). In some cases, PV will be used on rooftops or other dual-use applications, thus reducing land use below these estimates.
[84]

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[81] EcoLogo Criteria Document 003: Electricity – Renewable Low-impact (source: http://www.ecologo.org/common/assets/criterias/CCD-003.pdf).

[82] Electric Power Research Institute and the Office of Utility Technologies, Energy Efficiency and Renewable Energy, U.S. Department of Energy, "Renewable Energy Technology Characterizations" (1997). Available at <http://www1.eere.energy.gov/ba/pba/pdfs/entire_document.pdf> Accessed December 2007.

[83] Gipe, Paul. Wind Energy Comes of Age. John Wiley & Sons, Inc., Toronto (1995), p. 406

[84] Electric Power Research Institute op cit

Solar Thermal Electric Generators

In these systems, solar radiation is concentrated or focused to provide high temperatures, using a parabolic trough concentrator or mirrors focused on a central tower. A molten salt or other heat transfer fluid is used to run steam turbine generators.

Leakage of Heat Transfer Fluid:

The current heat transfer fluid (HTF) used in most parabolic trough systems (Therminol VP-1) is an aromatic hydrocarbon, biphenyl-diphenyl oxide. When spills occur, contaminated soil is removed to an on-site bio-remediation facility that utilizes indigenous bacteria in the soil to decompose the oil until the HTF concentrations have been reduced to acceptable levels. In addition to liquid spills, there is some level of HTF vapor emissions from valve packing and pump seals during normal operation. [85]

Land Use:

Parabolic trough plants require a significant amount of land that typically cannot be used concurrently for other uses. Parabolic troughs require the land to be graded level. A study for the state of Texas showed that land use requirements for parabolic trough plants are less that those of most other renewable technologies (wind, biomass, hydro) and also less than those of fossil fuels when mining and drilling requirements are included.[86] Current trough technology produces about 100 kWh/yr/m2 of land area.

The California Energy Commission estimates that solar thermal electricity technologies may require between 4 to 5 (1.6-2.0 Ha) acres per MW.[87]

Water Use:

Wet cooling towers are normally used with solar thermal electric power plants. If adequate water is not available at the power plant site, a dry condenser-cooling system could possibly be used. Dry cooling can reduce water needs by as much as 90%. However, if dry cooling is employed, cost and performance penalties are expected to raise levelized-energy costs by at least 10%.[88]

The land and water use values provided in Table 4 below apply to the solar portion of the power plant.

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[85] See Status Report on Solar Thermal Power Plants, Pilkington Solar International: 1996, and Holl, R.J., Status of Solar-Thermal Electric Technology, Electric Power Research Institute: 1989.

[86] Texas Renewable Virtus Energy Research Associates, "Energy Resource Assessment: Survey, Overview & Recommendations," prepared for the Texas Sustainable Energy Development Council (1995).

[87] Gipe, P. Wind Energy Comes of Age. John Wiley & Sons, Inc., Toronto (1995), p. 406

[88] Electric Power Research Institute and the Office of Utility Technologies, Energy Efficiency and Renewable Energy, U.S. Department of Energy, "Renewable Energy Technology Characterizations" (1997). Available at <http://www1.eere.energy.gov/ba/pba/pdfs/entire_document.pdf> Accessed December 2007.

SOLAR POWER TOWER

Table 4. Resource requirements.

Indicator Name	Units	Base Year 1997	2000	2005	2010	2020	2030
Land	ha/MWh/yr	$2.7x10^{-3}$	$1.5x10^{-3}$	$1.4x10^{-3}$	$1.3x10^{-3}$	$1.1x10^{-3}$	$1.1x10^{-3}$
Water	m^3/MWh	3.2	2.4	2.4	2.4	2.4	2.4

SOLAR PARABOLIC TROUGH

Table 4. Resource requirements [2].

Indicator Name	Units	Base Year 1997	2000	2005	2010	2020	2030
Plant Size	MW	30	80	161	320	320	320
Land	ha/MW	2.2	2.2	3.1	3.7	3.6	3.4
	ha	66	176	500	1,190	1,150	1,090
Water	m^3/MW-yr	18,500	14,900	17,500	21,900	21,900	21,900

Wind – onshore and near-shore

Capacity factors for wind are important in calculating actual effective capacity of turbines installed versus gross installed nameplate capacity. Average capacity factors are typically between approximately 30-40% depending on wind speeds.[89]

Once installed, wind energy enjoys the advantages of zero air, water and solid waste emissions. In addition, total fuel-cycle emissions, including emissions experienced during construction, fuel extraction (zero for wind) and operating cycles, are very low compared with all fossil fuels and many other types of generating technologies. These environmental advantages can help power companies meet environmental regulations and satisfy their customers' desire for clean power sources.

Avian Impacts:

Several potential localized impacts that wind farm designers and developers pay close attention to include avian interactions, visual or aesthetic impacts, land erosion around turbine pads or roads, and acoustic impacts. Wind power plants can affect local habitat and wildlife as well as people. The degree of impacts from these issues can vary from non-existent to critical, depending on site-specific characteristics of each project, e.g., proximity to human and avian population, type and use of surrounding land, and local preferences f or land use. Developers must carefully consider these characteristics when siting wind farms in order to mitigate potential impacts to acceptable levels.

[89] Wind capacity factors can be increased through the use of power storage systems but the environmental impacts of these systems are not addressed here.

Of the approximately 5 billion annual bird deaths reported in the United States, 200 million are a result of collisions with man-made objects. Experience over the past decade has shown that the level of bird mortality from interaction with wind farms can vary from none in some areas to levels of concern in others, such as where wind farms are sighted in migratory pathways or in dense avian population centers, such as Altamont Pass, California. Bird collisions with wind energy structures are the leading cause of mortality reported. Electrocutions are the second leading cause, but solutions have been developed to mitigate this problem. Other factors that influence the potential for avian collisions with wind energy facilities include land use, turbine design, turbine location, turbine orientation, operation methods, bird species, habitat use, and avian perching and flying behavior.[90]

Researchers performing studies at wind energy facilities in the United States and Europe report that mortalities are not considered biologically significant to overall populations, indicating that these impacts may be less than from many other man-made objects. In the U.S., bird deaths caused by wind turbines are currently just a small fraction of total anthropogenic bird deaths— estimated at less than 0.003% of the total in 2003.[91]

According to a study in *Nature*, each utility-scale wind turbine kills on average approximately 0.03 birds per year; of course, the type of bird killed is extremely important in determining overall impact to ecological integrity / biodiversity (i.e. the death of 10 common passerines such as the house sparrow [Passer domesticus] is likely to be far less consequential to biodiversity than the death of 10 birds of a more vulnerable species, such as the California condor [Gymnogyps californianus]).

However, regardless of the relative size of the impact from wind projects, minimizing the cumulative impacts on avian populations is still a critical requirement for wind energy growth domestically and abroad.

Visual Impacts:

The visual impact of wind turbines can be quite noticeable. Wind turbines are tall structures, often located on the tops of ridges and hills, and can be visible from relatively long distances. Experience shows that the layout of a wind power plant, type of tower, and color of the turbine and tower affect some people's aesthetic sensitivity. Finally, noise is caused by the air moving over the turbine blades (aerodynamic noise) and by the turbine's mechanical components. Engineers have reduced aerodynamic noise by design changes such as decreasing the thickness of the trailing edge of the blades and by orienting blades upwind of the tower. Since turbines still emit some noise, it is prudent for wind farm developers to consider proximity to residential areas when selecting development sites.[92]

Land Use:

Land does not have to be purchased/leased and dedicated exclusively for wind energy production. Long-term leases are quite common where co-uses such as livestock grazing reduce the cost to the wind farm owner while increasing the land value to the land owner.

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[90] Electric Power Research Institute and the Office of Utility Technologies, Energy Efficiency and Renewable Energy, U.S. Department of Energy, "Renewable Energy Technology Characterizations" (1997). Available at <http://www1.eere.energy.gov/ba/pba/pdfs/entire_document.pdf> Accessed December 2007.

[91] Erickson et al. "A Summary and Comparison of Bird Mortality from Anthropogenic Causes with an Emphasis on Collisions," USDA Forest Service General Technical Report PSW-GTR-191 (2005). Available online at <www.fs.fed.us/psw/publications/documents/psw_gtr191/Asilomar/pdfs/1029-1042.pdf>.

[92] Electric Power Research Institute and the Office of Utility Technologies, Energy Efficiency and Renewable Energy, U.S. Department of Energy, "Renewable Energy Technology Characterizations" (1997). Available at <http://www1.eere.energy.gov/ba/pba/pdfs/entire_document.pdf> Accessed December 2007.

Estimates based on existing projects suggest that wind farms may occupy between 14 and 100 acres per MW depending on project design,[93] although only 5-10% of that area is typically occupied by turbines. In rural areas, the remainder of the area can often be used for non-conflicting uses such as grazing and irrigation. [94],[95] However, the visual impact of a wind farm is dependent on the full occupied area. The United States' National Renewable Energy Lab estimates that actual land required for wind turbines is typically between 0.25 and 0.5 acres per turbine. The Sustainable Development Commission estimates that the land-take for an onshore wind power is around 180 hectares for 1,000 MW of capacity.[96]

Table 10. Resource requirements.

Indicator Name	Units	Base Year 1996	2000	2005	2010	2020	2030
WindFarm Size	MW	25	37.5	50	50	50	50
Land (50 turbines)							
5 turbines x 10 rows	ha/MW	33-20	26-16	24-15	24-15	24-15	24-15
	ha	825-500	975-600	1200-750	1200-750	1200-750	1200-750
25 turbines x 2 rows	ha/MW	19-26	15-21	14-19	14-19	14-19	14-19
	ha	475-650	563-788	700-950	700-950	700-950	700-950
50 turbines x 1 row	ha/MW	29-46	23-37	21-33	21-33	21-33	21-33
	ha	725-1150	863-1388	1050-1650	1050-1650	1050-1650	1050-1650
Water	m^3	0	0	0	0	0	0

Note: Range is for 2.5 rotor diameters (side) by 20 diameters (deep), and 5 diameters (side) by 10 diameters (deep)

[97]

Wind– Offshore

Off shore wind farms generally have higher capacity factor than onshore wind and are less visually intrusive than turbines on land, and result in less conflicting uses (generally marine "land" uses are more flexible than onshore land-use which may conflict with areas of good wind potential); however, transmission requirements are generally more extensive than for onshore wind (undersea cable construction).

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93 American Wind Energy Association. <www.aweo.org/windarea.html>

94 As of 2006, Paul Gipe's research indicates approximately 20 ha/MW, 50 a/MW, or 80-100 m^2 of land area/m^2 rotor swept area
www.wind-works.org/articles/BriefSummaryofWorldWindEnergyStats2006.html

95 <www.crest.org/repp_pubs/articles/envImp/04impacts.htm>

96 Sustainable Development Commission. "The Role of Nuclear Power in a Low Carbon Economy: Paper 3 – Landscape, Environment and Community Impacts of Nuclear Power," (2006). Available at <www.sd-commission.org.uk/publications/downloads/Nuclear-paper3-landscapeEnvironmentCommunity.pdf. Accessed November 2005>.

97 Electric Power Research Institute and the Office of Utility Technologies, Energy Efficiency and Renewable Energy, U.S. Department of Energy, "Renewable Energy Technology Characterizations" (1997). Available at <http://www1.eere.energy.gov/ba/pba/pdfs/entire_document.pdf>

According to a comprehensive 8-year study carried out by the Danish Energy Authority and the Danish Forest and Nature Agency, offshore wind turbines have exceedingly minor impacts on aquatic species and very little effect on bird mortality. The study concluded that major consequences from individual projects were unlikely.[98] However, it is important to note that cumulative impacts of offshore wind turbines are still subject to a large degree of uncertainty.

Biomass

The production of biomass feed-stocks for fuels, heat and power generation can have significant impact on land use, biodiversity, and other non-air environmental effects. Several agencies and organizations have assessed the potential impacts of biomass feedstock production in their development of sustainability guidelines. The following is a summary of impacts identified by Eco-Logo[99], The United States National Wildlife Federation[100], the Brazilian Forum of NGOs and Social Movements (FBOMS)[101], and the Energy Transition Task Force of the Netherlands.[102]

- Local competition for land, raw materials, water and labour associated with the production of food, building materials, energy supply and medicines.
- Degraded soil structure and fertility and inadequate crop residues.
- Reduction in biological diversity, both terrestrial and aquatic, and reduction of wildlife abundance and distribution.
- Negative impacts of monocultures, and use of persistent chemicals.
- Destruction of primary forests, native prairie/grasslands, or other areas containing high conservation values.
- Invasive species and GMO varieties.
- Wood-wastes and/or agricultural wastes that have been sourced from operations without sound environmental management practices, or from species that are listed in the CITES Appendices
- Use only dedicated energy crops that have been sourced from operations that have implemented a sound environmental management system and are adhering to.
- Unsustainable rates of harvest that exceed levels that can be sustained, and do nor use sound environmental management practices

Additional information can be found at the following web sites:

- Roundtable on Sustainable Palm Oil, Principles and Criteria for Sustainable Palm Oil Production, 17 October 2005; www.rspo.org

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[98] http://windpower.utah.edu/pdfs/danish_study.pdf
[99] EcoLogo Criteria Document 003: Electricity – Renewable Low-impact (source: http://www.ecologo.org/common/assets/criterias/CCD-003.pdf).
[100] *Selected Issues to be Addressed in Future Principles and Criteria for Sustainable Biofuels*, National Wildlife Federation.

[101] *Sustainability Criteria and Indicators for Bio-Energy*, Brazilian Forum of NGOs and Social Movements (FBOMS), February 2006. www.fboms.org.br/gtenergia/energia_doc.htm
[102] *Criteria for Sustainable Biomass Production*, Energy Transition Task Force of the Netherlands, July 14, 2006

- German NGO Forum on Environment and Development, Global Market for Bioenergy between Climate Protection and Development Policy, November, 2005; www.forumue.de
- Institute for Agriculture and Trade Policy, Sustainable Biomass Production Principles and Practices, 2003; www.iatp.org
- International Network for Sustainable Energy - Europe, "Criteria for Sustainable Use of Biomass Including Biofuels," April, 2006; www.inforse.org/europe
- Forest Stewardship Council, Principles and Criteria for Forest Stewardship, 1996; www.fsc.org
- Food and Agriculture Association of the United Nations. Bioenergy – Sustainability. http://www.fao.org/nr/ben/ben_key1_en.htm.

The following table provides some estimates of land use and water requirements for biomass fuelled power plants.[103]

Table 4. Resource requirements.

Indicator Name	Units	Base Year 1996	2000	2005	2010	2020	2030
Plant Size	MW	50	60	100	150	184	184
Land							
Plant	ha/MW	0.902	0.902	0.902	0.902	0.902	0.902
	ha	45.1	54.1	90.2	135.3	166.0	166.0
Crops	ha/MW	487	401	268	268	164	164
	ha	24,350	24,060	26,800	40,200	30,176	30,176
Crop Growth Rate	Mg/ha/yr	11.2	11.2	16.8	16.8	22.4	22.4
Power Plant Water	Mm^3/yr	0.808	0.808	1.341	2.012	2.426	2.426
Energy: Biomass	PJ/yr	5.35	5.35	8.90	13.34	13.34	13.34
Feedstocks: Biomass	Tg/yr	0.271	0.271	0.450	0.675	0.675	0.675
Labor							
Farm (261 ha/FTE)	FTE	95	95	101	152	114	114
Station	FTE	22	22	22	30	35	35

Note: FTE refers to full-time equivalent.

Geothermal-Hydrothermal[104]

Capacity factor: 90%+

In these systems, geothermally heated water or steam is used directly to produce power.

[103] Electric Power Research Institute and the Office of Utility Technologies, Energy Efficiency and Renewable Energy, U.S. Department of Energy, "Renewable Energy Technology Characterizations" (1997). Available at <http://www1.eere.energy.gov/ba/pba/pdfs/entire_document.pdf> Accessed December 2007.

[104] Electric Power Research Institute and the Office of Utility Technologies, Energy Efficiency and Renewable Energy, U.S. Department of Energy, "Renewable Energy Technology Characterizations" (1997). Available at <http://www1.eere.energy.gov/ba/pba/pdfs/entire_document.pdf>

***Land use**: 10 ha (10 hectare; 25 acres) for a 50 MW plant for direct occupancy for the power plant and surface disturbances due to wells and pipelines. The total well field area for the reference 50 MW flash plant is on the order of 160 ha (400 acres). These are estimates made from general information, and apply to either flash and or binary systems.*

***Water**: Water use for the reference dual flash plant is essentially nil because all of the cooling tower makeup come s from steam condensate, while still allowing the plant to meet typical requirements to re-inject at least 80 percent of the geothermal fluids produced. Because the binary plant characterized here is air cooled, it consumes no cooling water. With geothermal hydrothermal power generation, the biggest environmental concerns are the possible emissions of hydrogen sulphide and contamination of fresh water supplies with geothermal brines. Hydrogen sulphide emissions are abated, when necessary, with environmental control technology, and ground water contamination is avoided through protective well completion practices. Generally, there is les s possibility of adverse environmental impacts with hydrothermal binary generation than with hydrothermal flash generation because the hotter fluids used in flash plants tend to have greater concentrations of chemical contaminant s than do less hot fluids typically used in binary plants. Also, in binary plants that employ dry, rather than wet, cooling systems, the geothermal fluid remains in a closed system and is never exposed to the atmosphere before it is injected d back into the reservoir.*

Geothermal Hot Dry Rock[105]

Capacity factor = 80%+

In these systems, water is injected into geothermally heated rock and the resulting steam used to produce power.

***Land Use:** The land requirement is assumed to be similar to those for hydrothermal electric systems. It includes the land occupancy for the power plant and surface disturbances due to wells and pipelines. Roads to the site are not included. The unit land requirements decrease with larger plants. Land use for an HDR binary plant is expected to be minimal - ranging from about 6.1 ha (15 acres) for a 5 MW plant up to 10 ha (25 acres) for a 25 MW plant. Land disruption, erosion and sedimentation, and increased levels of human activity may adversely impact biological systems in the immediate vicinity of the plant and wells.*

Adverse visual impacts are also possible with HDR developments and would be of concern in inhabited areas and scenic areas. However, binary geothermal power plants are compact and have a very low profile compared to other industrial facilities.

***Water Use:** Water is required for drilling the deep HDR wells, and for fracturing the HDR reservoir rock. The amounts required are not quantified here. The system water "makeup" well would be drilled before the HDR deep wells are drilled; thus all water needed by the system except for that needed to drill the water well would come from that well. The power plant is designed with dry cooling towers, so there is no major water consumption by the power plant per se. All the water in a system with dry cooling remains in a closed loop and is never exposed to the atmosphere, limiting emissions to possible minor leaks of the working fluid around valves and pipe joints. When a wet cooling system is used, some water is lost to evaporation.*

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[105] Electric Power Research Institute , op cit

Although some water loss in the reservoir is expected with HDR systems, ground water contamination is not a concern for two reasons. First, it is probable that fresh water will be used in the system. Second, the depth and relative impermeability of the reservoir will lower the probability that the water used would migrate to shallow fresh water reservoirs.

Leakage around the boundaries of the reservoir may be anywhere from 5% to about 15% of the injection flow rate. Water consumption is about 2 to 6 m3/MWh in a 30 MW system. Larger losses are possible depending on the original permeability of the reservoir rock.

GEOTHERMAL HOT DRY ROCK

Table 2. Resource requirements.

Indicator Name	Units	Current Technology 1997	2020	2030
Net Plant Size	MW	5.06	14.78	29.57
Land Requirement	ha/MW	1.2	.55	.34
	ha	6.1	8.1	10.1
Water				
Injection Flow Rate	m^3/MWh	44.87	40.82	39.93
Estimated Water Consumption	m^3/MWh	2.24-6.73	2.04-6.12	2.0-5.99

Notes:

1. Water consumption is based on the rate of 5% to 15% of the injection rate.
2. The year 2000-2010 cases are not included in Table 2 because they are all single well triplet plant similar to the 1997 case