OCS Study
MMS 2007-013

# Assessing the Costs and Benefits of Electricity Generation Using Alternative Energy Resources on the Outer Continental Shelf

## Final Report

U.S. Department of the Interior
Minerals Management Service

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# Assessing the Costs and Benefits of Electricity Generation Using Alternative Energy Resources on the Outer Continental Shelf

## Final Report

Authors

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## 1.0 INTRODUCTION

Increasing the share of electricity generated by alternative sources of energy is widely recognized as an important element of any strategy to ensure future supplies of clean, affordable, and reliable power.[1] Among the resources available to help achieve this goal are those associated with the offshore environment, including wind energy, wave energy, and ocean current energy. Growing interest in the utilization of these resources to generate electricity has brought into focus the need for a better-defined regulatory framework to grant access to federal waters where development activities might occur.

The Energy Policy Act of 2005 initiated the creation of such a framework. Specifically, the Act included an amendment to Section 8 of the Outer Continental Shelf Lands Act (OCSLA, 43 U.S.C. 1337) authorizing the Department of the Interior to grant leases, easements, or rights-of-way on the U.S. Outer Continental Shelf (OCS)[2] for the development of alternative energy projects and to allow for alternate uses of existing OCS facilities (e.g., oil and gas platforms). The Department subsequently delegated this authority to the Minerals Management Service (MMS).

As an initial step in the development of a regulatory program, MMS is preparing a programmatic environmental impact statement (EIS). In general, the EIS identifies and qualitatively assesses the environmental, social-cultural, and economic considerations associated with different approaches for the establishment of a national offshore alternate energy-related use program. In response to comments received during the public scoping phase of the EIS, MMS engaged Industrial Economics, Incorporated (IEc) to prepare an objective analysis of the benefits and costs of offshore alternative energy projects. A benefit-cost analysis differs from an EIS in that it seeks to quantify and place monetary values on positive and negative impacts of a program or policy, thus enabling an assessment of whether the program's or policy's "total benefits" are likely to exceed "total costs" (i.e, whether the action analyzed is "net beneficial").

While offshore alternative energy projects will present benefits and costs similar in some respects to those associated with existing offshore energy facilities (i.e., those associated with oil and gas exploration and production), they will also give rise to benefits and costs that present new questions. The comments received in writing and during the series of 10 public meetings held during the scoping phase of the EIS clearly illustrate the range of impacts that MMS must factor into its decision-making processes.[3]

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[1] National Energy Policy: Report of the National Energy Policy Development Group, May 2001; Advanced Energy Initiative, National Economic Council, February 2006.

[2] The Outer Continental Shelf comprises the submerged lands, subsoil, and seabed, lying between the seaward extent of the States' jurisdiction (in most cases, three nautical miles, or approximately 3.3 statute miles, from shore), and the seaward extent of Federal jurisdiction (generally 200 nautical miles from shore).HH

[3] The public's comments addressed, *inter alia*, impacts on birds and other organisms as well as on marine habitats, emissions offsets, visual impacts, noise and vibration impacts, waste generation and disposal, water quality impacts, environmental justice.

## 1.1 Scope of Our Work

The principal benefit of completing a benefit-cost analysis at this stage of program development is the creation of a strong foundation for program development and future implementation. Consistent with the programmatic EIS, the timeframe of our analysis is 2007-2014. In all likelihood, relatively few offshore wind, wave, or ocean current projects, either commercial- or pilot-scale, will complete construction and begin generating electricity during this timeframe. However, the pioneer projects that do come on-line will serve as important catalysts for expanded development in the future *if* a system is put in place that seeks to maximize long-term net benefits. Arriving at such a system depends not only on an understanding of the types of costs and benefits associated with offshore development, but their relative weights and the degree of uncertainty associated with their quantification and monetization.

Before describing the scope of our analysis in greater detail, it is useful to describe what it is not.

1. Our work is not an analysis of whether use of the OCS for alternative energy projects is or is not net beneficial to society. We presume that Congressional action to amend the OCSLA and to authorize the granting of permits for such projects reflects the public's general approval of this activity, and that the current focus is on determining how best to evaluate development requests.

2. Our work is not an analysis of the aggregate benefits and costs of all alternative energy projects that might become operational on the OCS during the period 2007-2014. Such an analysis would require a more complete description of the type and scale of likely development than is currently available.

3. Our work is not a financial analysis; that is, we do not address the benefits and costs that could be realized by individual entities through interaction with an MMS regulatory program for offshore alternative energy development.

Our goal is to provide information concerning potential benefits and costs (in a social welfare context) that the public and government decision makers can use in the future as alternative energy development activities on the OCS arise.

The scope of our work comprised three phases. In the first phase, we considered the electric power market into which offshore alternative energy projects would sell electricity and the state of technological development for offshore wind, wave, and ocean current energy projects. We then developed representative "project profiles" for each technology, focusing on the characteristics that would influence the type and magnitude of potential social and environmental benefits and costs. Chapter 2 summarizes the results of this first phase.[4]

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[4] For our analysis of offshore alternative energy technologies, we depended greatly on the expertise of Dr. Jon McGowan and Mr. Chris Elkinton, who are affiliated with the Renewable Energy Research Laboratory at the University of Massachusetts.

In the second phase, we addressed the categories of benefits and costs that might be applicable to an analysis of offshore alternative energy projects (i.e., the benefits and costs of onshore generation alternatives as well as those associated with offshore alternative energy alternatives). Since our intent was to consider benefits and costs from a social welfare perspective, we focused on categories of impact that can be considered market "externalities." That is, we focused on those factors, such as ecological impacts of project construction, that are not incorporated into the market price of electricity. In an effort to capture the full range of potential benefits and costs, we considered categories of impact that could occur at each stage of a generation facility's life cycle (construction, fuel acquisition and transportation, operation and maintenance, and decommissioning). We then categorized the identified benefits and costs based on whether they can be quantified and monetized using existing, readily available data. Chapter 3 summarizes the second phase of our work.

The third phase of our work applies the Phase 2 taxonomy to the representative projects characterized in Phase 1 as a means to understand not only the relationship between the benefits and costs of offshore alternative energy projects but also the key data and analytic gaps that future research might address. Specifically, we examined the benefits and costs of the three representative offshore alternative energy projects relative to the onshore generation that these projects might displace. Since the degree of actual displacement of onshore generation by an offshore project would be dictated by a complex interrelationship of many factors,[5] the consideration of which is beyond the scope of our work, we examine two, simplified scenarios:

- Offshore alternative energy displaces coal-fired generation, under the presumption that this will provide an indication of the maximum difference in externalities between onshore and offshore generation;[6]

- Offshore alternative energy displaces a fuel mix that is proportional to the anticipated generation mix in the market region into which the offshore projects would supply electricity.

A third scenario would be the displacement of onshore wind energy, under the presumption that onshore wind is the most likely competitor for investment dollars that might instead go to offshore alternative energy projects. However, we do not have sufficient information to describe, in quantitative or monetary terms, the difference in net externalities between an onshore and an offshore project. Chapter 4 summarizes the third phase of our work.

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[5] A determination of which generation units would reduce their output in response to an increase in alternative energy supply depends on simultaneous consideration of factors such as when the power is being generated, fluctuations in fossil fuel prices, and transmission constraints.

[6] Because coal-fired power plants typically provide lower-cost, baseload generation, offshore alternative energy sources might be more likely to displace other generation sources.

## 2.0 MARKET AND TECHNOLOGY CHARACTERIZATION

The MMS programmatic EIS comes at an important juncture, where multiple stakeholders are asking fundamental questions about the future fuel mix for electricity generation and the economic and environmental implications of alternative generation technologies. For many years, alternative sources of energy other than conventional hydro have been studied, and often promoted, as potentially important complements to, if not substitutes for, the nation's current mix of fuels for electricity generation. And while the share of electricity generation from alternative energy sources has been essentially flat over the last 15 years (at approximately two percent of total generation), certain sectors such as wind and solar energy have experienced substantial recent growth in absolute terms, driven by a confluence of forces including technological maturation, relative economic performance improvement, and environmental concerns associated with fossil fuels.

At the utility-scale, the recent elevation in the profile of alternative energy is largely attributable, on a generation basis, to the wind industry. Total wind energy capacity in the United States recently surpassed 11,000 megawatts (MW), an increase of 350 percent since 2000 when total capacity stood at just over 2,500 MW. This rapid capacity increase is in part a function of the development of a new generation of multi-megawatt turbines. As turbine technology has matured attention has turned to the potential for offshore development, where wind speed (a critical factor in the economics of wind energy) is generally both greater and more consistent than it is onshore, creating attractive economic opportunities for the deployment of turbines larger than any likely to be sited onshore.

Wind is not the only potential energy resource in the offshore environment. Both waves and ocean currents offer commercial-scale development possibilities, though they must still overcome a variety of technical and cost hurdles before they can achieve true commercial viability.[7] While the technology needed to harness wave and ocean current energy is just beginning to be demonstrated, the growth of an offshore wind industry could contribute to an acceleration of the pace of development of these other ocean resources.

The purpose of this chapter is to present a sound basis for identifying the potential costs and benefits of using offshore resources (specifically wind, wave, and ocean current resources within federal waters) for electricity generation. While it is possible to identify benefit and cost categories in the abstract (i.e., in the absence of specific project examples), the exercise of developing representative projects of certain types, sizes, and locations is helpful in ensuring that we do not overlook any benefit or cost categories that might be dependent upon a specific project parameter (e.g., location, since human uses of offshore resources that may be affected by energy projects might differ at alternative locations).

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[7] One such hurdle is the development of widely accepted engineering standards (for testing, construction, operation, etc.) required to attract private capital to offshore energy projects. Standards for wind energy projects are already emerging. The development of standards for wave energy is at a very early stage. We are unaware of any organized efforts to develop standards for ocean current energy projects.

The remainder of this chapter begins with a description of baseline electric utility industry conditions. We then consider offshore wind, wave, and ocean current technologies separately, with an emphasis on three key characteristics that are most relevant to the identification and quantification of benefits and costs: location, generating capacity/output, and project "footprint" (i.e., how large a "site" the project would occupy and what its physical impact, if any, would be on the seafloor). At the end of each technology subsection we describe a project that can be considered representative of those that might enter into operation during the period 2007-2014. These projects will serve as the basis for our consideration of benefits and costs in Chapter 4.

## 2.1 Baseline Electric Utility Industry Conditions

The following description of electric utility conditions is intended to illustrate the market into which offshore alternative energy capacity and generation would be introduced during the period 2007-2014. In developing this summary, we rely on data compiled by the U.S. Department of Energy's Energy Information Administration (EIA), specifically data provided in the most recent version (2006 edition) of EIA's Annual Energy Outlook (AEO).[8]

The baseline characterization in this report reflects the reference case in the AEO, which projects electric power capacity and generation based simply on existing conditions and trends. In other words, the reference case does not assume any policy or market changes that might alter the pace, type, or location of generating capacity additions or retirements. As such, the reference case in the AEO is often viewed as overly conservative (i.e., more likely to understate changes than overstate them), particularly with respect to alternative energy technologies. Nevertheless, it provides a useful starting point given that alternative energy has been and, in the near term, will remain a relatively small component of the overall energy mix with respect to electric power generation.[9]

## 2.2 Current U.S. Energy Mix

According to EIA, the U.S. electric power sector produced approximately 3,971 billion kilowatt-hours (kWh) in 2004, predominantly through the use of conventional sources.[10] As Figure 2-1 illustrates, electricity derived from coal burning power plants represented 50 percent of 2004 U.S. production while nuclear power sources produced approximately 20 percent of the nation’s electricity (EIA 2006a). Natural gas and petroleum sources produced approximately 18 and three percent of the total, respectively. Conventional hydropower represented the majority of

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[8] The 2006 Annual Energy Outlook was released in February 2006. An updated AEO (AEO 2007) is scheduled to be available in February 2007.

[9] EIA also develops a “high renewables scenario” in which future energy generation capacity for 2010 and 2030 is forecast assuming more rapid adoption of renewable technologies. In 2010, the high renewables estimates are greater than the reference case by less than one percent. By 2030, this difference has increased to roughly 34 percent, the majority of which is higher predictions of biomass production, an electricity source not considered in this analysis.

[10] 2004 is the most recent year for which data are currently available from EIA to describe generation from all energy sources.

production by alternative sources, at nearly seven percent of total generation. Excluding conventional hydro, alternative energy sources accounted for less than three percent of U.S. electricity production.

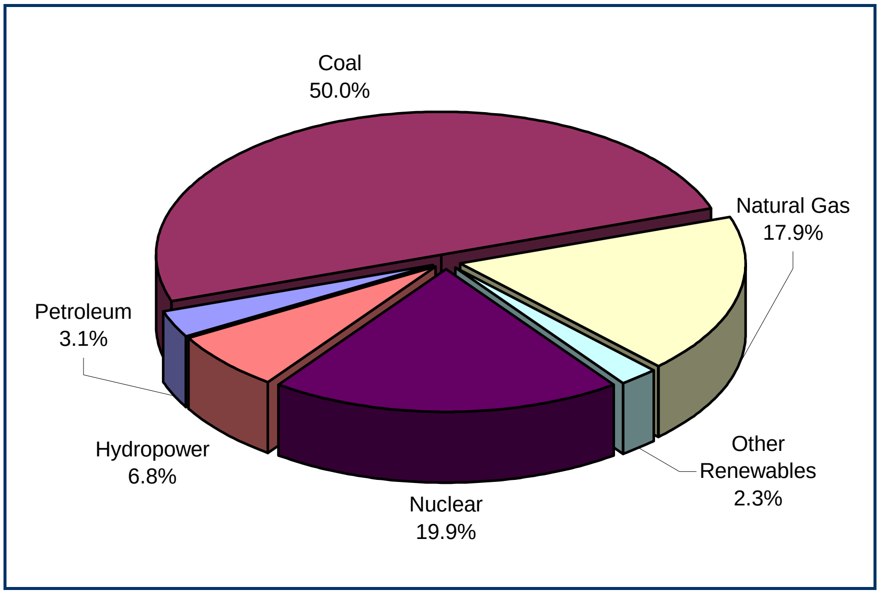

Figure 2-1. 2004 U.S. Electricity Production by Source.

As illustrated in Figure 2-2, the majority of this electricity generation in 2004 was derived from biomass (50.2 percent), geothermal (24.6 percent), and wind resources (24.2 percent) (EIA 2006b).[11] Solar power constitutes only one percent of the Nation’s alternative energy mix, excluding conventional hydro (0.02 percent of the total). In EIA's reporting, biomass is a broad category that includes:

- Wood and wood waste;
- Municipal solid waste and landfill gas; and
- "Other" biomass, including "agriculture byproducts/crops, sludge waste, tires, and other biomass solids, liquids and gases."

The MSW/landfill gas category accounted for more than 60 percent of the biomass generation reported by EIA. Approximately 32 percent of biomass-fueled electricity production is associated with wood and wood waste, and nearly all of this total is derived from pulp and paper industry processes.

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[11] As a result of capacity additions in the last two years, wind resources now provide more electricity than geothermal resources.

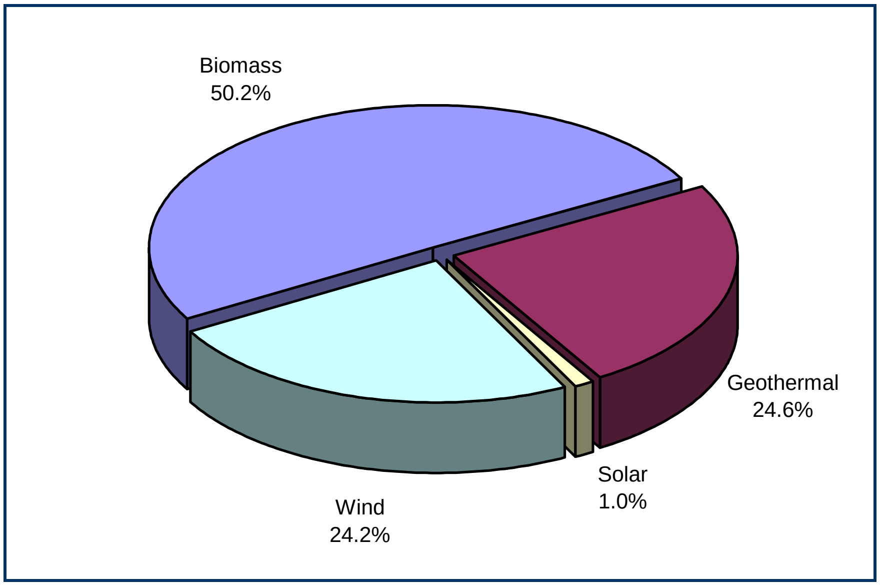

Figure 2-2. 2004 U.S. Electricity Production by Alternative Energy Source, Excluding Conventional Hydro.

## 2.3 Regional Energy Mixes During Period of Analysis

We made the simplifying assumption that the fuel mix within the electric power sector would remain constant during the period of analysis. We examined this assumption in greater detail by reviewing EIA's specific, reference case projections for both electric power capacity and generation during the period 2007-2014 in the eight market regions that include a coastal component (i.e., regions that would absorb generation from offshore alternative energy sources). As illustrated in Figure 2-3, these regions include (from northeast to northwest):

- Northeast Power Coordinating Council - New England;
- Northeast Power Coordinating Council - New York;
- Mid-Atlantic Area Council;
- Southeastern Electric Reliability Council;
- Florida Reliability Coordinating Council;
- Electric Reliability Council of Texas;
- Western Electricity Coordinating Council - California; and
- Western Electricity Coordinating Council - Northwest Power Pool Area.

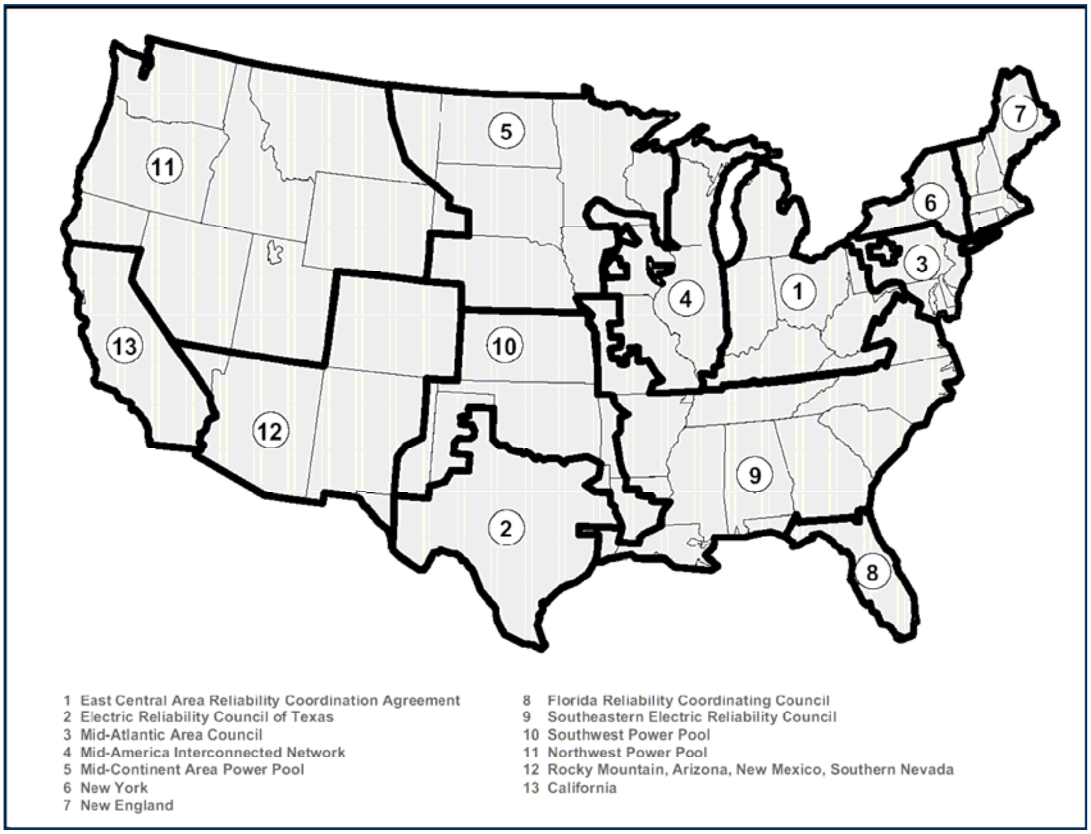

Figure 2-3. EIA Electricity Market Module Regions.

Data describing electric power capacity and generation projections by year for each region are contained in the AEO Supplemental Tables, which were generated for the reference case of the AEO using the National Energy Modeling System (NEMS). These projections serve as the basis for describing the power generation that might be "displaced" by an offshore project (specifically, the displacement of equivalent generation from a mix of onshore technologies proportional to the regional generation profile).

## 2.4 Wind Energy

Of the three technologies we are considering, wind energy is the most technologically mature and the closest to commercial-scale deployment in the U.S. offshore environment, with two projects in advanced planning stages and a variety of others at least at the exploration stage. The large amount of research and analysis that has accompanied the development of this technology (particularly in Europe, where several offshore wind projects are currently operational), combined with the extensive wind energy experience that has already been gained in the onshore environment, makes it possible to be fairly specific about the types of projects that could come online during the analysis period. Key factors to consider in constructing a "representative" project profile include the physical characteristics (including the quality of the wind resource) in alternative locations and the state of wind turbine technology, both of which will influence the footprint of offshore projects.

### 2.4.1 Location

Until floating turbine support structures are shown to be reliable and cost-effective (which we do not expect will occur during the analysis period), offshore wind energy development in federal waters will likely be limited to areas where the depth to the seafloor is 80 meters (262.5 feet) or less. In the immediate future, development is more likely to occur in even shallower waters, with depths up to approximately 30 meters (98.4 feet). As a result, development is likely to occur first along the Atlantic coast or in the Gulf of Mexico, where these conditions exist at suitable distances from the shore.[12] Development in these regions will be driven by the factors that most directly influence the economic feasibility of potential projects, namely the quality of the resource, the local cost of electricity, and any programs that provide subsidies or other incentives for wind projects. Wind energy projects will be most competitive, and thus most likely to be developed, in locations with better wind resources and relatively high electricity costs. Figure 2-4 depicts the regions available for offshore wind energy project development.

### 2.4.2 Technology

Wind turbines for offshore applications are currently in the 2.5-3.6 MW class, with ongoing development and testing of turbines in the 5MW (and larger) class. During the period 2007-2014, we assume that turbines larger than 5MW will not penetrate the market to a significant degree. A number of technical characteristics are relevant to the consideration of a wind project's environmental impacts. The hub height for 2.5-5 MW turbines ranges from approximately 75-90 meters (246.1-295.3 feet) (though the actual height above water is dependent on site-specific conditions). Rotor diameters in this class range from approximately 80-120 meters (262.5-394.7 feet). At present, the most common turbine support sub-structure (i.e., the portion of the structure fixed to the seabed), and the most likely to be utilized in federal waters, is the monopile, which has a diameter of approximately four to six meters (13.1 to 19.7 feet) for turbines of this size. Transmission cables to onshore grid connection points are typically buried in backfilled trenches that are approximately one meter (3.3 feet) wide and originate at an offshore substation. Total wind farm capacities will likely vary by region. In the Atlantic and Gulf Coast regions proposals for projects in the 100-500 MW range may be typical (though projects with total capacity of up to 1,000 MW have been proposed).[13]

Table 2-1 summarizes by region the characteristics that will influence offshore wind project development.

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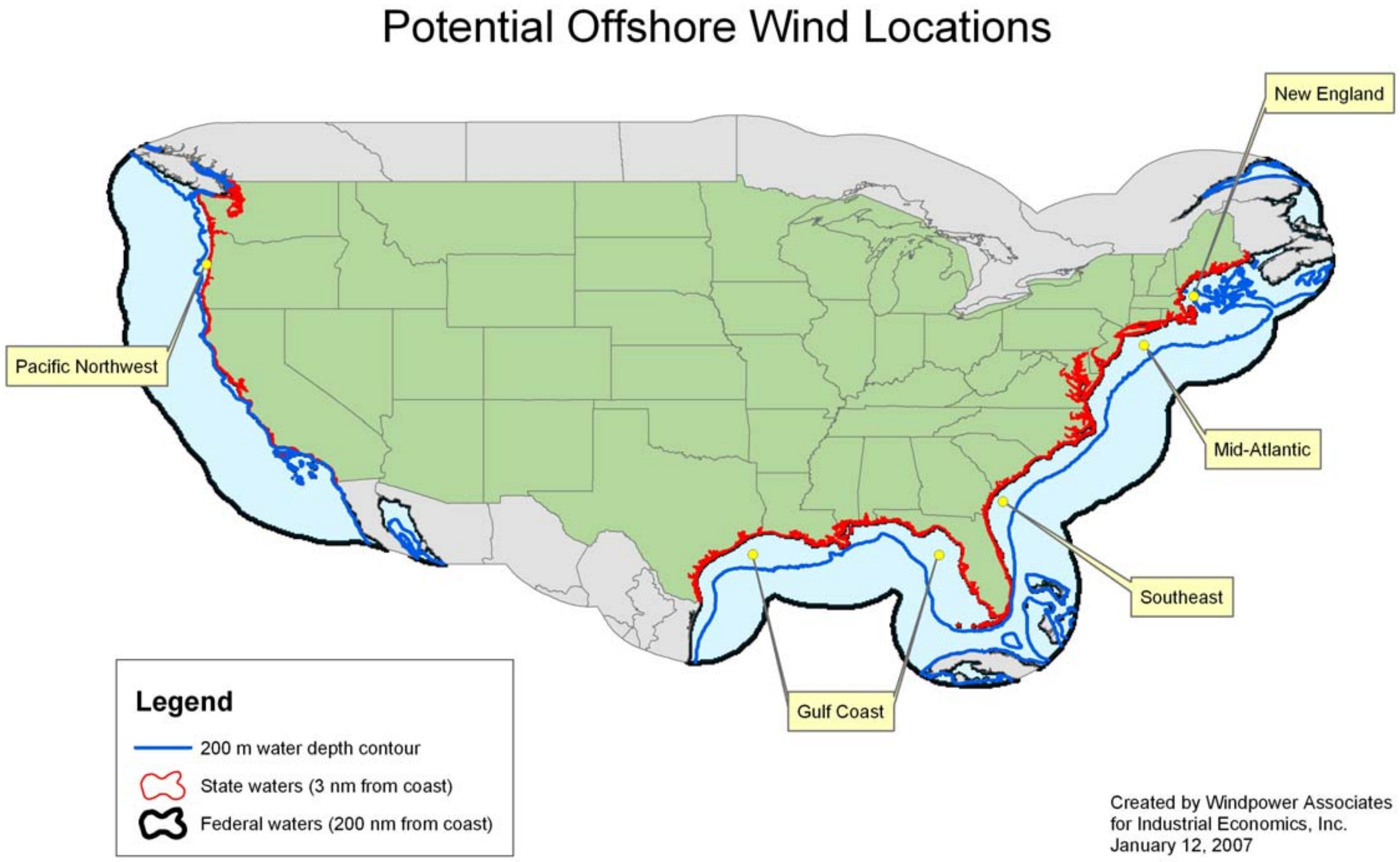
[12] We assume that large-scale, commercial wind energy projects located in federal waters will be sited as far from shore as possible, subject to maximum water depth wind quality constraints, in order to minimize real or perceived aesthetic impacts.

[13] In comparison, electricity generating plants that use fossil or nuclear fuel typically have nameplate capacities of 500 to more than 1,000 MW.



Note: State jurisdiction off the Texas and Florida Gulf coasts extends to a maximum of 3 marine leagues (16.2 km or 10 miles) into the Gulf of Mexico.

Figure 2-4. Locations For Potential Offshore Wind Energy Development.

Table 2-1

Region-Specific Characteristics Relevant To OCS Wind Energy Development

| Region | Wind Speed m/s (mph) | Capacity Factor | Capacity Potential (GW)* | | Potentially Developable Area km$^2$ (mi$^2$)** | |
|---|---|---|---|---|---|---|
| | | | 0-30m depth (0-98.4 feet) | 30-60m depth (98.4-197 ft) | 0-30m depth (0-98.4 ft) | 30-60m depth (98.4-197 ft) |
| Mid-Atlantic | 7 - 8 (15.7 - 17.9) | 30 - 40% | 64.3 | 126.2 | 7,000 (2,700) | 20,000 (7,720) |
| New England | 8 - 10 (17.9 - 22.4) | 40 - 50% | 10.3 | 43.5 | 2,500 (965) | 1,500 (579) |
| Gulf of Mexico | No data | No data | Not assessed | Not assessed | 45,000 (17,400) | 75,000 (29,000) |
| Southeast | 7 - 8 (15.7 - 17.9) | 30 - 40% | Not assessed | Not assessed | 30,000 (11,600) | 45,000 (17,400) |
| Pacific | 6 - 9 (13.4 - 20.1) | 20 - 45% | 0 | 1.9 | Very little | Very little |

* Based on information provided in Musial and Butterfield (2004)

** Federal waters only; restricted and protected areas not accounted for.

### 2.4.3 Representative Project

Based on the information above, the representative wind energy project we will use in our analysis has the following characteristics.

- Located in federal waters off the mid-Atlantic coast.
- Nameplate capacity of 360 MW (3.6 MW per turbine x 100).
- Capacity factor of 35 percent, resulting in annual generation of approximately 1.1 million megawatt hours (MWh).
- Total project footprint of approximately 40 square kilometers (15.4 square miles) (based on typical spacing between turbines).
- Seafloor footprint of individual turbines of approximately 20 square meters (215 square feet).
- One-meter (3.3-foot) wide backfilled trench for transmission cable.
- Operational starting in 2010.
- Operating lifetime of 25 years.

Table 2-2 present's EIA's projection of the electricity generation mix in the market region into which this representative project would deliver power.

Table 2-2

EIA Electric Power Projections - Mid-Atlantic Area Council

| | **2007** | | **2010** | |
|---|---|---|---|---|
| **CAPACITY (GIGAWATTS)** | | | | |
| **Source** | **Capacity** | **Share of Total** | **Capacity** | **Share of Total** |
| Coal Steam | 20.67 | 29.09% | 20.67 | 29.08% |
| Other Fossil Steam | 8.03 | 11.31% | 8.03 | 11.30% |
| Combined Cycle | 13.16 | 18.53% | 13.16 | 18.52% |
| Combustion Turbine/Diesel | 12.30 | 17.31% | 12.31 | 17.32% |
| Nuclear Power | 13.30 | 18.72% | 13.33 | 18.75% |
| Pumped Storage/Other | 1.54 | 2.17% | 1.54 | 2.17% |
| Conventional Hydropower | 1.22 | 1.72% | 1.22 | 1.72% |
| Municipal Solid Waste | 0.69 | 0.97% | 0.69 | 0.97% |
| Wood and Other Biomass | 0.03 | 0.04% | 0.03 | 0.04% |
| Wind | 0.10 | 0.14% | 0.10 | 0.14% |
| **GENERATION (BILLION KILOWATT-HOURS)** | | | | |
| **Fuel Type** | **Generation** | **Share of Total** | **Generation** | **Share of Total** |
| Coal | 133.57 | 47.11% | 145.23 | 48.74% |
| Petroleum | 7.43 | 2.62% | 7.68 | 2.58% |
| Natural Gas | 21.43 | 7.56% | 24.41 | 8.19% |
| Nuclear | 108.08 | 38.12% | 108.47 | 36.41% |
| Conventional Hydropower | 4.61 | 1.63% | 4.61 | 1.55% |
| Municipal Solid Waste | 4.78 | 1.69% | 4.78 | 1.60% |
| Wood and Other Biomass | 3.34 | 1.18% | 2.48 | 0.83% |
| Wind | 0.28 | 0.10% | 0.28 | 0.10% |

Source: Energy Information Administration, Supplemental Tables to the Annual Energy Outlook 2006, Tables 62 and 78.

## 2.5 Wave Energy

Our specification of a representative offshore wave energy project relies primarily on work completed by the Electric Power Research Institute's (EPRI) Wave Energy Conversion (WEC) Project (EPRI 2004, 2005; Bedard 2006). It is important to note, however, that the primary objective of the EPRI project is to investigate the technical and economic feasibility of wave energy projects in the United States, culminating in the development of at least one pilot-scale project that can further aid the investigation of technological feasibility. However, EPRI project documentation is sufficient to develop a description of a wave energy project that might feasibly become operational during the 2007-2014 time period.

### 2.5.1 Location

The EPRI work suggests that the most significant wave energy development in the near term is likely to occur in the shallow state waters off Hawaii, which is outside the geographic scope of our analysis. EPRI assessed potential wave energy project locations on the Atlantic and Pacific coasts on the basis of bathymetry and seafloor geology, robustness of coastal utility grids, relative cost of electricity (since the first wave energy projects will likely deliver power at a relatively high market price), regional infrastructure (capable of supporting fabrication and maintenance of WEC hardware), and potential conflicts with other uses of ocean resources, including proximity to protected natural areas such as National Marine Sanctuaries. The results of this analysis are summarized in Table 2-3.

Table 2-3

Summary of EPRI Evaluation of Near-Term Opportunities for Wave Energy Development

| **State** | **Wave Resource Quality** | **Coastal Infrastructure** | **Market Conditions** |
|---|---|---|---|
| California (Northern) | Excellent | Excellent | Relatively high electricity prices |
| Oregon | Excellent | Excellent | Relatively low electricity prices* |
| Washington | Very good | Limited in certain areas (e.g., north coast to Seattle) | Relatively low electricity prices* |
| Massachusetts | Good in winter, poor in summer | Good | Relatively high prices, current market for renewable energy certificates |
| Maine | Relatively poor | Good in selected locations | Relatively high prices |
| * The availability of conventional hydroelectric power is a significant factor in the local cost of electricity. | | | |

### 2.5.2 Technology

EPRI identified, and requested information from, 17 developers of WEC devices. From this group, eight devices were judged to warrant further consideration with respect to their potential for near-term pilot- or commercial-scale deployment. Table 2-4 provides general, single-device characteristics of these eight technologies.

## Table 2-4

## Characteristics of Individual Wave Energy Conversion Devices

| **Technology** | **Type** | **Length m (ft)** | **Width m (ft)** | **Rated Power (kw)** | **Assumed Capacity Factor (%)** | **Centerline Spacing m (ft)** | **Mooring System** | **Mooring Depth m (ft)** |
|---|---|---|---|---|---|---|---|---|
| **Aqua Energy "Aqua Buoy"** | Free-floating point absorber | 6 (19.7) | 6 (19.7) | up to 250 | 40 | NA | Slack mooring | > 50 (164) |
| **Energetech** | Oscillating water column | 25 (82.0) | 35 (115) | 500 - 2,000 | 33 | 60-90 (197-295) | Chained to 4 driven piles | up to 50 (164) |
| **Independent Natural Resources "Seadog"** | Bottom mounted point absorber | 5.4 (17.7) | 5.4 (17.7) | variable | 40 | 20 (65.6) | Anchored to concrete slabs | 20 (65.6) |
| **Ocean Power Delivery "Pelamis"** | Floating attenuator | 120 (394) | 4.6 (15.1) | 500 | 40 | 150 (492) | Slack mooring | at least 50 (164) |
| **Orecon** | Floating oscillating water column | 32 (105) | 32 (105) | 1,000 | 50 | 100 (328) | 6-point catenary mooring | > 50 (164) |
| **Teamwork "Wave Swing"** | Bottom mounted point absorber | 9.5 (31.2) | 9.5 (31.2) | 4,000 | 20 | 80 (263) | Gravity base | 43 (141) |
| **Wavebob** | Floating point absorber | 15 (49.2) | 15 (49.2) | 250 - 1,000 | 40 | 50 (164) | 3-point catenary mooring | > 50 (164) |
| **Wave Dragon** | Floating overtopping ramp | 150 (492) | 260 (492) | 4,000 | 34 | 700 (2,300) | Catenary mooring | > 25 (82.0) |

Source: EPRI 2004

### 2.5.3 Representative Project

Characterization of the range of "typical" wave energy projects is difficult given the substantial amount of site assessment, technology development, and testing work that is still required before commercial deployment. For our analysis we are primarily interested in the physical characteristics of individual energy conversion devices, the total area occupied by a potential project, and the associated scale of electricity production. The EPRI work provides the only information currently available to us that includes all of these elements; specifically, EPRI developed conceptual designs for commercial-scale projects, using the Energetech and Pelamis technologies, that could produce approximately 300,000 MWh/year. Based on communication with EPRI (Bedard 2006) our representative project utilizes the Pelamis technology and has the following characteristics.

- Located in federal waters off the Oregon coast.
- Nameplate capacity of 90 MW (500 kW per unit x 180).
- Capacity factor of approximately 40 percent, resulting in annual generation of approximately 300,000 MWh.
- Total project footprint of approximately 16 square kilometers (6.2 square miles) (4 clusters of 45 units, each cluster occupying an area 2.25 x 1.8 km).
- One-meter (3.3-foot) wide backfilled trench for transmission cable.
- Operational starting in 2012.
- Operating lifetime of 20 years.

Table 2-5 present's EIA's projection of the electricity generation mix in the market region into which this representative project would deliver power.

## Table 2-5

## EIA Electric Power Projections - Western Electricity Coordinating Council - Northwest Power Pool Area

| | **2007** | | **2012** | |
|---|---|---|---|---|
| **CAPACITY (GIGAWATTS)** | | | | |
| **Source** | **Capacity** | **Share of Total** | **Capacity** | **Share of Total** |
| Coal Steam | 11.21 | 18.6% | 11.21 | 18.68% |
| Other Fossil Steam | 0.77 | 1.3% | 0.28 | 0.47% |
| Combined Cycle | 6.94 | 11.5% | 6.94 | 11.57% |
| Combustion Turbine/Diesel | 2.58 | 4.3% | 2.08 | 3.46% |
| Nuclear Power | 1.11 | 1.8% | 1.11 | 1.85% |
| Pumped Storage/Other | 0.31 | 0.5% | 0.31 | 0.52% |
| Conventional Hydropower | 35.28 | 58.5% | 35.28 | 58.81% |
| Geothermal | 0.27 | 0.4% | 0.79 | 1.32% |
| Municipal Solid Waste | 0.08 | 0.1% | 0.08 | 0.14% |
| Wood and Other Biomass | 0.24 | 0.4% | 0.24 | 0.39% |
| Wind | 1.53 | 2.5% | 0.02 | 0.03% |
| **GENERATION (BILLION KILOWATT-HOURS)** | | | | |
| **Fuel Type** | **Generation** | **Share Of Total** | **Generation** | **Share Of Total** |
| Coal | 80.37 | 30.5% | 82.54 | 29.27% |
| Petroleum | 1.17 | 0.4% | 1.11 | 0.40% |
| Natural Gas | 16.15 | 6.1% | 24.77 | 8.78% |
| Nuclear | 8.86 | 3.4% | 8.88 | 3.15% |
| Conventional Hydropower | 148.52 | 56.4% | 148.52 | 52.66% |
| Geothermal | 2.34 | 0.9% | 8.18 | 2.90% |
| Municipal Solid Waste | 0.57 | 0.2% | 0.57 | 0.20% |
| Wood and Other Biomass | 0.11 | 0.0% | 1.57 | 0.56% |
| Wind | 5.20 | 2.0% | 0.04 | 0.01% |

Source: Energy Information Administration, Supplemental Tables to the Annual Energy Outlook 2006, Tables 70 and 86.

## 2.6 Ocean Current Energy

Of the three types of generation technologies that MMS is interested in examining, those designed to extract energy from offshore ocean currents (different from projects utilizing near-shore tidal currents that would not be within MMS's jurisdiction) are likely the furthest from commercial-scale deployment and thus present the greatest challenge with respect to describing a representative project for the 2007-2014 timeframe.

### 2.6.1 Location

At present, project development in federal waters is focused exclusively on the portion of the Gulf Stream located off the east coast of Florida (the "Florida Current"). It is perhaps worth noting that this resource has been recognized for its power production potential for at least three decades (Lissaman and Radkey 1979). The Florida Current is perhaps the only offshore location (in federal waters) that exhibits the characteristics necessary for successful siting of a marine current project, as summarized by Fraenkel (2002):

- Fast flowing water;
- A relatively uniform seabed to minimize turbulence;
- Sufficient water depth to allow for installation of large turbines;
- Existence of the above conditions over a large enough area to allow for installation of an array of turbines that can make the project cost-effective; and
- Proximity to an onshore grid connection.

At least two entities have received preliminary permits from the Federal Energy Regulatory Commission (FERC) to explore development opportunities at multiple sites within the Current, offshore from the Florida Keys north to approximately Port St. Lucie, Florida.[14] Both entities are currently at the technology development and testing phase. Technical, financial, and regulatory hurdles remain to be addressed before commercial deployment is feasible; however, given the fact that permitted exploration activities are ongoing, it is not unreasonable to forecast development of at least one commercial project by 2014.

### 2.6.2 Technology

The public filings to FERC (including permit applications and required progress reports) of the two project development entities we are aware of describe two different project configurations:

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[14] "The purpose of a preliminary permit is to maintain a priority of application for a license during the term of the permit while the permittee conducts investigations and secures data necessary to determine the feasibility of the proposed project and, if the project is found to be feasible, prepares an acceptable development application." (FERC 2005)

Configuration A

- Twin-rotor machine, with blades approximately 21.3 meters (70 feet) in diameter, suspended at a depth of 61.0 meters (200 feet) beneath a 45.7-meter (150-foot) long ballast tank and moored to an anchor on the seabed

- Single unit nameplate capacity of 2 to 3 MW.

- Cluster(s) of 8 machines occupying approximately 2.6 square kilometers (one square mile) per cluster at the western edge of the Florida Current (total nameplate capacity per cluster of approximately 16 to 24 MW).

- Interconnection transmission line to onshore load.

Configuration B

- Twin-rotor machine, with blades approximately 20 meters (65.6 feet) in diameter, mounted on wings on either side of a three meter diameter tubular steel monopile drilled into the seafloor at a depth of 18.3 to 36.6 meters (60 to 120 feet).

- Single unit nameplate capacity of 550 to 1,200 kW.

- Clusters of 20 to 40 machines occupying an area of 2.6 square kilometers (one square mile) or less per cluster at the western edge of the Florida Current (total nameplate capacity of approximately 20 to 40 MW).

- Interconnection transmission line to onshore load.

### 2.6.3 Representative Project

Given that (1) a prototype of the technology associated with Configuration B has been tested in a field trial in Europe, and (2) the environmental impact of this technology may be greater due to its placement on the seafloor (and thus may be more informative in terms of considering maximum potential impacts), we assume that this technology would be the one deployed during the analysis period.

- Located in federal waters up to 24 kilometers (15 miles) off the Florida coast in the area between Miami and West Palm Beach.

- Nameplate capacity of 20 MW (1 MW per unit x 20).

- Capacity factor of approximately 80 percent, resulting in annual generation of approximately 140,000 MWh.

- Total project footprint of approximately 1.5 square kilometers (0.6 square miles).

- One-meter (3.3-foot) wide backfilled trench for transmission cable.

- Operational starting in 2014 (given the need for additional testing and scale-up to commercial size machines, the need for additional studies to determine the optimal size and specific location of commercial projects, and the various permitting steps that will need to be taken, including completion of environmental and other impact assessments that permitting will require).

- Operating lifetime of 20 years.

Table 2-6 present's EIA's projection of the electricity generation mix in the market region into which this representative project would deliver power.

Table 2-6

EIA Electric Power Projections - Florida Reliability Coordinating Council

| | **2007** | | **2014** | |
|---|---|---|---|---|
| **CAPACITY (GIGAWATTS)** | | | | |
| **Source** | **Capacity** | **Share of Total** | **Capacity** | **Share Of Total** |
| Coal Steam | 10.39 | 19.9% | 11.77 | 20.9% |
| Other Fossil Steam | 10.61 | 20.3% | 10.26 | 18.3% |
| Combined Cycle | 16.24 | 31.1% | 18.70 | 33.3% |
| Combustion Turbine/Diesel | 10.38 | 19.9% | 10.83 | 19.3% |
| Nuclear Power | 3.90 | 7.5% | 3.96 | 7.1% |
| Conventional Hydropower | 0.05 | 0.1% | 0.05 | 0.1% |
| Municipal Solid Waste | 0.46 | 0.9% | 0.46 | 0.8% |
| Wood and Other Biomass | 0.14 | 0.3% | 0.14 | 0.3% |
| **GENERATION (BILLION KILOWATT-HOURS)** | | | | |
| **Fuel Type** | **Generation** | **Share Of Total** | **Generation** | **Share Of Total** |
| Coal | 71.33 | 37.0% | 83.84 | 35.7% |
| Petroleum | 26.30 | 13.7% | 28.83 | 12.3% |
| Natural Gas | 57.54 | 29.9% | 83.47 | 35.6% |
| Nuclear | 32.24 | 16.7% | 32.61 | 13.9% |
| Conventional Hydropower | 0.02 | 0.01% | 0.02 | 0.01% |
| Municipal Solid Waste | 3.08 | 1.6% | 3.08 | 1.3% |
| Wood and Other Biomass | 2.17 | 1.1% | 2.86 | 1.2% |

Source: Energy Information Administration, Supplemental Tables to the Annual Energy Outlook 2006, Tables 67 and 83.

# 3.0 BENEFIT AND COST TAXONOMY

This chapter presents a taxonomy of potential impacts relevant to a benefit-cost analysis of offshore alternative energy projects. As noted in Chapter 1, our focus is on benefits and costs that meet the definition of an "externality," or an impact associated with the generation of electricity that is a real benefit or cost to society (either presently or in the future) but that is not incorporated into the price of electricity. This focus is appropriate given the goal of a benefit-cost analysis, which is to assess the net social benefits associated with alternative means of achieving a specified public goal (Sassone and Schaffer 1978). Consideration of externalities as they apply to various electricity generation technologies is of particular importance, since the difference in the values of externalities associated with generation from two technologies may exceed the difference in price.

We divide the remainder of this chapter into three sections. The first section describes the system we use to categorize benefits and costs. The second section describes, in general, how we further categorize benefits and costs according to whether we can readily quantify and monetize them using existing information. The third section provides more detailed descriptions of benefits and costs associated with different resources used for electricity generation.

## 3.1 General Categorization

The first step in categorizing potential benefits and costs is determining the relevant scope of the analysis. We have concluded that, at this level of analysis, it is appropriate to limit the scope to the benefits and costs associated with the types of electricity generation that offshore wind, waves, and ocean currents might be displacing. Therefore, we consider externalities associated with offshore alternative energy plus those associated with coal, natural gas, oil, nuclear, and conventional hydroelectric power.[15,16] Furthermore, at this level of analysis we do not see significant differences in the types of benefits and costs associated with the offshore alternative energy options, and thus consider them as a single type. Similarly, we group together the fossil fuel-based generation alternatives (coal, gas, and oil). Nuclear and conventional hydropower have sufficiently distinguishing characteristics to consider each separately.

In order to capture all relevant benefit and cost categories associated with electricity generation, we classify externalities in life cycle subcategories, including construction; fuel acquisition and transportation; operations and maintenance; and waste and decommissioning. We also organize benefits and costs into four broad categories (environmental, socioeconomic, national/energy security, and human health) as summarized below and in Table 3-1. Given our externality focus, we do not consider taxes or subsidies. Subsidies are transfer payments between the government

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[15] Among the other alternative energy resources that contribute to electricity supply, onshore wind is perhaps the most relevant in terms of scale. However, we do not consider this resource separately because its externalities are not expected to be substantially different from those associated with offshore wind. Potentially significant qualitative differences between onshore and offshore wind are highlighted later in this chapter.

[16] While it is common to consider alternative means of supplying electricity, it is also appropriate to consider the option of reducing demand through conservation. We assume there are no externalities associated with conservation, and thus do not include it in our detailed analysis.

## Table 3-1

## Categories Of Significant Benefits and Costs

| **BENEFIT OR COST** | **DESCRIPTION** |
|---|---|
| **ENVIRONMENTAL** | |
| Net diminishment or impairment of habitat and ecosystems due to footprint of generating facility | Ecosystem impacts caused by the presence of the generating facility in the environment. "Net" impacts are considered since some benefits may be generated in some cases (e.g., artificial reef). |
| Degradation of ecosystems associated with non-greenhouse gas emissions | Ecosystem damage caused directly or indirectly by atmospheric emissions other than greenhouse gases (e.g., by acid rain caused by emissions from fossil fuel combustion). |
| Degradation of ecosystem associated with waste production (chemical or thermal) | Impairment or degradation of an ecosystem due to discharge of waste (e.g., fish mortality associated with once-through cooling water). |
| Ecosystem degradation associated with fuel extraction | Degradation of ecosystems caused by mining processes, such as the injury caused by surface coal mines. |
| Net degradation of ecosystems associated with greenhouse gas emissions | Ecosystem damages potentially associated with climate change caused by the release of greenhouse gases (e.g., changes in storm intensity and frequency, climate shifts, sea level rise, and other potential effects). "Net" effects are considered, since some benefits may result from climate change (e.g., faster growth of some forests in U.S.). |
| **SOCIOECONOMIC** | |
| Net decrease in economic activity associated with non-greenhouse gas emissions | Economic losses caused by the direct and indirect effects of non-greenhouse gas emissions (e.g., agricultural losses associated with acid rain). |

Table 3-1 (cont.)

| **BENEFIT OR COST** | **DESCRIPTION** |
|---|---|
| Net effect on visibility and aesthetic resources | Economic impact of diminished view quality due to the presence of mining or generating facilities or atmospheric haze from emissions (e.g., views diminished by offshore wind turbines). "Net" impacts are considered since some benefits may be derived from perceived visual improvements (e.g., views improved by wind turbines). |
| Net decline in tourism or recreation opportunities | Net loss or gain in recreation and tourism (e.g., from conventional hydroelectric reservoir construction). |
| Loss or degradation of cultural resources | Damage to archaeological or other cultural resources from the footprint or secondary effects of a generating facility. |
| Economic impacts of greenhouse gas emissions | Loss in commercial activity or other economic impact due to changes in storm intensity and frequency, rising sea levels, or other potential effects of climate change. |
| Water supply security and flood control | Benefits to region of decreased likelihood of floods and increased water availability from construction of a conventional hydroelectric reservoir (e.g., more reliable supply of irrigation water). |
| **NATIONAL/ENERGY SECURITY** | |
| Possible target for acts of terrorism | Impacts on national security from potential attacks on a sensitive energy generating facility. |
| Energy independence | National security benefits from increased reliance on domestic sources of energy. |
| **HUMAN HEALTH** | |
| Increased human health risks associated with non-greenhouse gas emissions | Respiratory illnesses and other health impacts caused by atmospheric releases from fossil fuel generation. |
| Human health risk of potentially catastrophic events | Mortality and morbidity from a large-scale generation facility catastrophe, such as the collapse of a dam or a nuclear accident. |

Table 3-1 (cont.)

| **BENEFIT OR COST** | **DESCRIPTION** |
|---|---|
| Human health risk from potential releases of hazardous materials | Mortality and morbidity risk from potential releases of wastes that are hazardous to human health, such as radionuclides and crude oil. |
| Human health risks associated with greenhouse gas emissions | Risks associated with increased storm intensity and frequency, rising sea levels, shifting climates, and other potential effects of climate change caused by the release of greenhouse gases. |

and producers, and are thus internalized into production decisions (by producers and by society), putting them beyond the scope of this analysis. Note that we refer to “net” changes associated with a particular externality, reflecting the fact that an externality potentially has positive *and* negative components (e.g., the economic effects of climate change, which may be positive in some areas and negative in others).

Each mode of electricity generation results in a broad range of life cycle benefits and costs. Rather than develop a comprehensive list of these externalities, we develop a general categorization of the most significant benefits and costs in terms of presumed magnitude.[17] Given a lack of available information in some cases, the decision to include or exclude certain benefits and costs is based in part on professional judgment. We recognize that there are specific impacts (particularly potential costs) that may be viewed as especially significant by certain stakeholders, but that we have not included in our taxonomy (e.g., the potential for offshore projects to alter the character of waves reaching shore in a way that diminishes surfing experiences). While we acknowledge the potential relevance of such impacts, our analysis is focused on those benefits and costs that we believe are most likely to have the most significant influence (positive or negative) on whether a project is net beneficial.

### 3.1.1 Environmental Externalities

Positive and negative externalities associated with the environment fall into two general categories. The first includes the direct physical impacts of electricity generation and related activities, including the impact of the "footprint" of generation facilities. Examples of these impacts include inundation of habitat by a reservoir formed behind a conventional hydroelectric dam, landscape scarring caused by mining operations, and bird mortality associated with wind turbines. A second category of environmental impact involves benefits and costs associated with the generation of atmospheric emissions and waste streams released to the natural environment, particularly during operation of a generation facility. Non-greenhouse gas emissions cause environmental degradation and health effects, while greenhouse gases may produce a wide variety of impacts associated with climate change. Other considerations include the potentially negative human health and environmental effects associated with discharges of hazardous waste and once-through cooling water.

### 3.1.2 Socioeconomic Externalities

Socioeconomic externalities associated with the electricity generation include a wide range of social, cultural, and direct economic impacts. For example, during one or more phases of an electricity generation life cycle there can be positive or negative impacts related to viewsheds, regional tourism, recreational activities, and cultural resources. In general, well-established methodologies exist to measure or estimate the magnitude of these impacts.

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[17] For example, although offshore alternative energy sources produce some atmospheric emissions during the construction phase of their life cycle (e.g., emissions of vessels delivering construction materials to the site), these are not included as costs due to their relative insignificance compared to emissions from fossil fuel combustion.

### 3.1.3 National/Energy Security Externalities

National/energy security externalities include the potential risks to national security of providing potential targets for terrorism and the potential benefits associated with increasing U.S. energy independence. Risks to national security can be based on vulnerability to either large-scale human health impacts (e.g., by targeting nuclear facilities) or energy supply disruption, resulting in destabilizing impacts on regional economies (e.g., from targeting sensitive critical elements of the energy infrastructure). The more concentrated an electricity source (e.g. a 1,000 megawatt nuclear facility versus distributed photovoltaic cells in residential areas), the greater potential for significant economic impacts.

### 3.1.4 Human Health Externalities

Human health externalities are associated with (1) the generation of atmospheric emissions and waste streams (e.g., greenhouse gases, sulfur dioxide ($SO_2$) emissions, mining wastes released to surface water), and (2) the impact of low-probability, high-risk events (e.g., catastrophic nuclear accidents). In a comparison of emitting and non-emitting energy alternatives, we can tally either the costs associated with emissions from fossil fuel combustion or the benefits of avoiding emissions through the use of alternative energy resources.

## 3.2 Approach to Quantification and Monetization

A complete benefit cost analysis would include quantified *and* monetized measures of all significant benefits and costs. The first offshore alternative energy projects in Europe are gaining valuable operational experience, leading not only to a greater understanding of their external benefits and costs but also to research and data collection that allow for measurement of the scale and value of these impacts. The addition of projects in the U.S. market will add to this growing body of knowledge. At present, however, the benefit and cost literature associated with offshore alternative energy remains limited, particularly with respect to the monetization of externalities.

To provide an initial assessment of the "state of the art," we further categorize individual benefits and costs according to whether they are readily monetizable, quantifiable but non-monetizable, or non-quantifiable. We define “readily” to mean that credible, well-established, social welfare-based unit values exist in the literature (i.e., original research is not required). While it may be possible, using existing methodologies and original research, to monetize benefits and costs that we categorize as quantifiable but not monetizable, we do not believe sufficient research currently exists to undertake site-specific monetization based on values reported in peer-reviewed literature. Table 3-2 summarizes our approach to categorizing benefits and costs along this dimension.

An example of a readily monetizable externality may be the complex but well-studied impacts of atmospheric fossil fuel emissions on human health. Studies have monetized these impacts by first quantifying the health effects related to emissions, then by linking those health impacts to monetary effects such as additional health care costs borne by individuals and society. Quantifiable but non-monetizable externalities include factors such as bird mortality (associated with wind turbines, for example), which may be quantifiable but lack credible supporting literature to support monetization. An external cost or benefit is categorized as non-quantifiable when no single, generally-accepted metric is available to count or value the externality. For example, no clear metric exists to quantify the energy security provided by generating electricity at offshore facilities.

Table 3-2
Classification Scheme for Externality Characterization

| **Classification** | **Definition** | **Example** |
|---|---|---|
| Not applicable | An externality considered inapplicable or relatively insignificant compared to others evaluated in the analysis. | Emissions associated with offshore alternative energy production |
| Not readily quantifiable | An important externality that cannot be readily quantified using a single, generally-accepted metric. | Energy security |
| Not monetizable using readily available data | An externality that is quantifiable, but not readily monetizable without additional research. | Biota mortality |
| Monetizable, at least in part, using readily available data | A positive or negative externality that is supported by well-established quantification and monetization methodologies. | Human health effects associated with atmospheric emissions from fossil fuel combustion |

Table 3-3 applies the classification scheme shown above to the benefits and costs listed in Table 3-1. Empty (white) cells indicate our belief that the particular benefit or cost is not applicable in the context of a particular generation type. We classify certain impacts as monetizable "at least in part" because the externality values that are available (see Chapter 4) are based on categories that do not correspond exactly to our taxonomy.

## 3.3 Description of Specific Benefits and Costs

In this section, we describe environmental, socioeconomic, national/energy security, and human health externalities associated with each of the electricity generation resources included in our analysis.

### 3.3.1 Fossil Resources

The most significant costs associated with electricity generation using fossil fuel resources are associated with atmospheric emissions, effluent (including thermal discharges), and disposal of waste. Table 3-4 summarizes our judgment regarding the current ability to quantify or monetize relevant benefits and costs associated with fossil-fuel based electricity generation.

Table 3-3

Characterization of Benefits and Costs of Electricity Generation by Fuel Type

☐ Not Applicable ░ Not readily quantifiable ▒ Not monetizable using readily available data ■ Monetizable, at least in part, using readily available data

| BENEFIT OR COST | RESOURCE | | | |
|---|---|---|---|---|
| | FOSSIL | NUCLEAR | WIND, WAVE,CURRENT | CONVENTIONAL HYDRO |
| **ENVIRONMENTAL** | | | | |
| Net diminishment or impairment of habitat and ecosystems due to footprint of generating facility | ▒ | ▒ | ▒ | ▒ |
| Degradation of ecosystems associated with non-greenhouse gas emissions | ▒ | ☐ | ☐ | ☐ |
| Degradation of ecosystem associated with waste production (chemical or thermal) | ▒ | ▒ | ☐ | ☐ |
| Ecosystem degradation associated with fuel extraction | ░ | ░ | ☐ | ☐ |
| Net degradation of ecosystems associated with greenhouse gas emissions | ░ | ☐ | ☐ | ☐ |
| **SOCIOECONOMI**C | | | | |
| Net decrease in economic activity associated with non-greenhouse gas emissions | ■ | ☐ | ☐ | ☐ |
| Net effect on visibility and aesthetic factors | ▒ | ▒ | ▒ | ☐ |
| Net decline in tourism or recreation opportunities | ▒ | ▒ | ▒ | ■ |
| Loss or degradation of cultural resources | ▒ | ▒ | ▒ | ▒ |
| Economic impacts of greenhouse gas emissions | ■ | ☐ | ☐ | ☐ |
| Water supply security and flood control | ☐ | ☐ | ☐ | ■ |
| **NATIONAL/ENERGY SECURITY** | | | | |
| Possible target for acts of terrorism | ☐ | ░ | ☐ | ░ |
| Energy independence | ░ | ░ | ░ | ░ |
| **HUMAN HEALTH** | | | | |
| Increased human health risks associated with non-greenhouse gas emissions | ■ | ☐ | ☐ | ☐ |
| Human health risk of potentially catastrophic events | ☐ | ■ | ☐ | ▒ |
| Human health risk from potential releases of hazardous materials | ▒ | ■ | ☐ | ▒ |
| Human health risks associated with greenhouse gas emissions | ■ | ☐ | ☐ | ☐ |

## Table 3-4

## Life-Cycle Benefits and Costs Associated with Fossil Fuel-Based Electricity Generation

□ Not Applicable
░ Not readily quantifiable
▒ Not monetizable using readily available data
▓ Monetizable, at least in part, using readily available data

| **BENEFIT OR COST** | **LIFE CYCLE PHASE** | | | |
|---|---|---|---|---|
| | **CONSTRUCTION** | **FUEL ACQUISITION & TRANSPORTATION** | **OPERATIONS & MAINTENANCE** | **WASTE & DECOMMISSIONING** |
| **ENVIRONMENTAL** | | | | |
| Net diminishment or impairment of habitat and ecosystems due to footprint of generating facility | ▒ | □ | □ | □ |
| Degradation of ecosystems associated with non-greenhouse gas emissions | □ | □ | ▒ | □ |
| Degradation of ecosystem associated with waste production (chemical or thermal) | □ | □ | ▒ | □ |
| Ecosystem degradation associated with fuel extraction | □ | ░ | □ | □ |
| Net degradation of ecosystems associated with greenhouse gas emissions | □ | □ | ░ | □ |
| **SOCIOECONOMIC** | | | | |
| Net decrease in economic activity associated with non-greenhouse gas emissions | □ | □ | ▓ | □ |
| Net effect on visibility and aesthetic factors | □ | ▒ | ▒ | □ |
| Net decline in tourism or recreation opportunities | □ | ▒ | ▒ | □ |
| Loss or degradation of cultural resources | ▒ | ▒ | □ | □ |
| Economic impacts of greenhouse gas emissions | □ | □ | ▓ | □ |
| Water supply security and flood control | □ | □ | □ | □ |
| **NATIONAL/ENERGY SECURITY** | | | | |
| Possible target for acts of terrorism | □ | □ | □ | □ |
| Energy independence (domestic fuels for electricity generation) | □ | □ | ░ | □ |
| **HUMAN HEALTH** | | | | |
| Increased human health risks associated with non-greenhouse gas emissions | □ | □ | ▓ | □ |
| Human health risk of potentially catastrophic events | □ | □ | □ | □ |
| Human health risk from potential releases of hazardous materials | □ | ▒ | □ | ▒ |
| Human health risks associated with greenhouse gas emissions | □ | □ | ▓ | □ |

#### 3.3.1.1 Environmental Externalities

Environmental externalities associated with fossil fuel combustion are well-studied. Atmospheric emissions from fossil fuels impose the highest external costs, but the footprints of the mining and generation facilities are also significant.

- The establishment and operation of generation or mining facilities may result in habitat loss or degradation. This is particularly true of surface coal mining, which may affect large areas of land.

- The ecosystem and environmental impacts of atmospheric emissions of non-greenhouse gases have been well-studied. In particular, nitrogen oxides ($NO_X$) and $SO_2$, which are the building blocks of acid rain, result in the acidification of lakes and soils. These compounds originate mainly from coal combustion, although oil and natural gas combustion produce them as well (see for example Burtraw et al. 1998).

- Power plants that run on fossil fuels are often situated adjacent to water bodies in order to provide a source for cooling water, referred to as “once-through cooling water.” Both thermal effects and the withdrawal of water can affect aquatic environments (Unsworth 2005).

- While oil is not a major fuel source for electricity, oil-fired facilities' need for fuel delivery may increase the chance of oil spills.

- The waste ash from coal purification and combustion can be highly acidic and can pollute surface and groundwater systems.

- Combustion of fossil fuels (especially coal) is a major source of greenhouse gases and thus contributes to climate change. Although not readily quantifiable, the impacts of climate change on ecosystems could be considerable (IPCC 2001), although the direction of these changes on a local basis (e.g., decreases or increases in species’ populations) cannot be generalized.

#### 3.3.1.2 Socioeconomic Externalities

Emissions associated with fossil fuel combustion are the principal driver of socioeconomic externalities.

- A decrease in economic activity (e.g., acid rain's impact on agriculture and buildings) can be attributed to non-greenhouse gas emissions (see for example Burtraw et al. 1998).

- Property values adjacent to mining and generation facilities may decline due to emissions and visual quality effects.

- Both the presence of the physical facility and perceptions of negative health effects may cause declines in tourism and recreation.

- Acid rain deposition and the footprint of the mining facilities and power plant may cause loss or deterioration of cultural resources.

- Climate change-related socioeconomic externalities associated with greenhouse gas emissions are generally, though not always, categorized as costs. Certain effects, such as increased storm surges and rising sea levels will have a net negative impact, though others may generate benefits as well as costs, depending on geographic location (e.g., some areas may experience economic benefits from warmer temperatures).

#### 3.3.1.3 National/Energy Security Externalities

The physical infrastructure associated with fossil fuel mining and power generation is not considered to be a major target for terrorism, but the fuel and electricity infrastructure that supports this generation may be of greater concern. For example, Liquefied Natural Gas (LNG) is increasingly being transported by tanker and gasified at central terminals, providing a potential target for supply disruption.

Electricity generated from coal and natural gas contributes to energy independence because of the large U.S. resource reserves. However, this benefit cannot be readily quantified.

#### 3.3.1.4 Human Health Externalities

Human health risks associated with fossil fuel combustion are attributable to emissions and to the working environment in mines.

- Risks are associated with non-greenhouse gas emissions, including particulates, ozone, $SO_2$, $NO_x$, and mercury (primarily from coal combustion) (see for example EPA 2003).

- Potential releases of hazardous materials during either transportation (e.g., oil spills) or waste production (e.g., coal slag) can potentially contaminate groundwater and surface water supplies and lead to adverse human health effects.

- Collisions while transporting coal by rail may cause injuries or mortalities.

Existing research begins to monetize human health impacts associated with climate change resulting from greenhouse gas emissions (see for example Guo et al. 2006).

### 3.3.2 Nuclear

The benefit-cost profile associated with nuclear energy is considerably different than the profiles of other electricity generation resources included in this analysis because many of the external costs are based on low probability, high consequence risks. These external costs and benefits have been quantified and monetized where feasible by various studies (see for example NEA

2003). Nuclear power has identifiable externalities at each life cycle phase, from construction, to uranium acquisition and transportation, to power plant operation and maintenance (O&M), and finally to waste production, transportation, storage, and decommissioning. Table 3-5 summarizes our judgment regarding the current ability to quantify or monetize relevant benefits and costs associated with nuclear electricity generation.

#### 3.3.2.1 Environmental

The most significant environmental externality associated with nuclear power is the potential for releases of radioactive materials from waste repositories. Other potential impacts associated with the nuclear power life cycle include the following.

- Habitat and ecosystems are likely to be impaired by the presence of the mining and generation facilities.

- Although nuclear power does not produce significant amounts of atmospheric emissions, the need for once-through cooling water in the generation process produces thermal impacts that can negatively affect organisms in streams or lakes.

- Releases from uranium mining operations can degrade surface water and groundwater quality.

#### 3.3.2.2 Socioeconomic Externalities

External socioeconomic costs attributable to nuclear power production center on decreased land values, declines in tourism or recreational opportunities, and a loss of cultural resources.

- Atmospheric emissions, uranium mining operations, and the power facility each negatively affect visual resources, likely having an effect on property values (for example see Gamble and Downing 1982).[18]

- As with other resources, the construction of a uranium mine or nuclear power plant may affect tourism and recreational opportunities.

- Losses of cultural resources may result from power plant construction or uranium mining operations.

#### 3.3.2.3 National/Energy Security Externalities

Nuclear power has the most pronounced set of external national security costs. Nuclear power facilities (as well as nuclear waste repositories) are potential targets for terrorist attacks. Furthermore, since these facilities typically generate significant amounts of power in a single

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[18] Overall, local property values may increase or decrease in response to the construction of a power generation facility depending on perception of health risk, visual impacts, noise impacts, additional employment opportunities, as well as other factors.

## Table 3-5

## Life-Cycle Benefits and Costs Associated with Nuclear Electricity Generation

☐ Not Applicable
░ Not readily quantifiable
▒ Not monetizable using readily available data
■ Monetizable, at least in part, using readily available data

| **BENEFIT OR COST** | **LIFE CYCLE PHASE** | | | |
|---|---|---|---|---|
| | **CONSTRUCTION** | **FUEL ACQUISITION & TRANSPORTATION** | **OPERATIONS & MAINTENANCE** | **WASTE & DECOMMISSIONING** |
| **ENVIRONMENTAL** | | | | |
| Net diminishment or impairment of habitat and ecosystems due to footprint of generating facility | ▒ | | | |
| Degradation of ecosystems associated with non-greenhouse gas emissions | | | | |
| Degradation of ecosystem associated with waste production (chemical or thermal) | | | ▒ | |
| Ecosystem degradation associated with fuel extraction | | ░ | | |
| Net degradation of ecosystems associated with greenhouse gas emissions | | | | |
| **SOCIOECONOMIC** | | | | |
| Net decrease in economic activity associated with non-greenhouse gas emissions | | | | |
| Net effect on visibility and aesthetic factors | | ▒ | ▒ | |
| Net decline in tourism or recreation opportunities | | ▒ | ▒ | |
| Loss or degradation of cultural resources | ▒ | ▒ | | |
| Economic impacts of greenhouse gas emissions | | | | |
| Water supply security and flood control | | | | |
| **NATIONAL/ENERGY SECURITY** | | | | |
| Possible target for acts of terrorism | | | ░ | ░ |
| Energy independence | | | ░ | |
| **HUMAN HEALTH** | | | | |
| Increased human health risks associated with non-greenhouse gas emissions | | | | |
| Human health risk of potentially catastrophic events | | | ■ | ■ |
| Human health risk from potential releases of hazardous materials | | | ■ | ■ |
| Human health risks associated with greenhouse gas emissions | | | | |

location, such an attack could significantly disrupt regional power supply. Since uranium is produced both domestically and in Canada, use of nuclear power can also beneficially contribute to greater energy independence.

#### 3.3.2.4 Human Health Externalities

Although catastrophic events related to nuclear power are extremely rare, the potential consequences of a nuclear accident are severe. Potential external costs to human health include risks associated with catastrophic nuclear accidents and risks of leaking nuclear wastes, in addition to any disutility caused by the fear of such occurrences. These risks cannot be readily quantified or monetized.

### 3.3.3 Offshore Wind, Wave, and Ocean Current Resources

The most important costs associated with the generation of electricity using offshore alternative energy resources will likely be their physical footprint in the natural and human environments.[19] Among the benefits of offshore alternative energy is the avoidance of costs associated with fossil fuel-based electricity generation, particularly the impact of resource extraction and transportation and combustion-related atmospheric emissions. For each externality summarized below, we indicate whether it represents a negative or positive impact (i.e., cost or benefit). We have not attempted to characterize the relative magnitudes of these costs and benefits, as they will vary depending on site-specific circumstances. Table 3-6 summarizes our judgment regarding the current ability to quantify or monetize relevant benefits and costs associated with offshore alternative electricity generation.

We note that studies of the costs associated with offshore wind farms (particularly environmental impacts) are ongoing based on the performance of the first generation of European projects.[20] Prospective studies of the potential impacts of U.S. offshore development exist, while detailed studies of the anticipated impact of the first generation of U.S. wind farm projects are in development.[21] While these studies generally do not go beyond the quantification of specific impacts, they can serve as useful foundations for future examinations of costs and benefits on a monetary basis. A list of studies that examine offshore alternative energy externalities is provided as Appendix A.

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[19] We assume that, during the licensing process, sensitive ecological areas, marine transportation corridors, and other sensitive area will be ruled out as possible locations of offshore generation facilities.

[20] See for example Danish Offshore Wind - Key Environmental Issues. Published by DONG Energy, Vattenfall, The Danish Energy Authority, and The Danish Forest and Nature Agency. November 2006. (Hhttp://www.ens.dk/sw42947.aspH) Additionally, the web site of the majority owner of the Horns Rev offshore wind project in Denmark offers a wide range of reports on the environmental impact of this project, one of the first large-scale, commercial offshore wind farms (Hhttp://www.vattenfall.com/H).HH

[21] See for example McKenna, E.J., T.P. Dillingham, T.J. Korth, B.J. McCay, S.A. Weiner, and D. Wieland. 2006. State of New Jersey Blue Ribbon Panel on Development of Wind Turbine Facilities in Coastal Waters.

Table 3-6

Life Cycle Benefits and Costs Associated with Offshore Alternative Electricity Generation

| **BENEFIT OR COST**<br>☐ Not Applicable<br>░ Not readily quantifiable<br>▒ Not monetizable using readily available data<br>▓ Monetizable, at least in part, using readily available data | **LIFE CYCLE PHASE** | | | |
|---|---|---|---|---|
| | **CONSTRUCTION** | **FUEL ACQUISITION & TRANSPORTATION** | **OPERATIONS & MAINTENANCE** | **WASTE & DECOMMISSIONING** |
| **ENVIRONMENTAL** | | | | |
| Net diminishment or impairment of habitat and ecosystems due to footprint of generating facility | ▒ | | ▒ | |
| Degradation of ecosystems associated with non-greenhouse gas emissions | | | | |
| Degradation of ecosystem associated with waste production (chemical or thermal) | | | | |
| Ecosystem degradation associated with fuel extraction | | | | |
| Net degradation of ecosystems associated with greenhouse gas emissions | | | | |
| **SOCIOECONOMIC** | | | | |
| Net decrease in economic activity associated with non-greenhouse gas emissions | | | | |
| Net effect on visibility and aesthetic factors | ▒ | | ▒ | |
| Net decline in tourism or recreation opportunities | | | ▒ | |
| Loss or degradation of cultural resources | ▒ | | | |
| Economic impacts of greenhouse gas emissions | | | | |
| Water supply security and flood control | | | | |
| **NATIONAL/ENERGY SECURITY** | | | | |
| Possible target for acts of terrorism | | | | |
| Energy independence | | | ░ | |
| **HUMAN HEALTH** | | | | |
| Increased human health risks associated with non-greenhouse gas emissions | | | | |
| Human health risk of potentially catastrophic events | | | | |
| Human health risk from potential releases of hazardous materials | | | | |
| Human health risks associated with greenhouse gas emissions | | | | |

Although the availability of studies describing monetary estimates of the impacts of offshore alternative energy projects is very limited, the economics literature does contain a wide range of studies that value similar types of externalities (e.g., studies have monetized the value of avian populations in a variety of contexts, generating data that could be reviewed for its applicability to the valuation of avian mortality associated with wind turbines). We provide in Appendix B a list of selected studies that may be useful to future assessments of the benefits and costs of individual offshore alternative energy projects.

#### 3.3.3.1 Environmental Externalities

Offshore alternative energy facilities may diminish, impair, or augment marine and near shore habitats during the construction or O&M processes.

- Avian interactions (cost). Marine bird mortality and disruption of migratory patterns could result from collisions with wind towers and turbines.[22]

- Noise impacts to marine mammals, sea turtles, and fish (cost). Marine organisms may be adversely affected by the presence of continuous or intermittent noise produced by offshore facilities. Although studies have evaluated the effect of noise on marine organisms (e.g., research on the effect of sonar), we are unaware of any that have monetized this externality.

- Artificial reef effects from scour pads or other seafloor interfaces (benefit). Reef growth (and therefore benthic habitat) may be enhanced by the presence of offshore facilities. Although the recreational and ecological benefits associated with reefs have been studied in other contexts, they are highly dependent on site-specific characteristics (e.g., density of marine organisms, depth, frequency and duration of recreation).

#### 3.3.3.2 Socioeconomic Externalities

Offshore wind, wave, and current facilities are also expected to generate external socioeconomic costs and benefits associated with their life cycle.

- Competition with commercial fishing (cost). The placement of offshore energy facilities may compete with regional fishing operations, potentially negatively affecting the local economy. The effects on fisheries of other marine disturbances (such as power facilities that entrain fish while drawing in sea water for cooling) have been studied previously, but these effects are highly site-specific.

- Visual impacts (uncertain effect). The construction of offshore technologies may diminish visual resources along nearby coastlines, with a potential negative effect on

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[22] See for example Johnson, L.A., 2006. Massachusetts Audubon Society's position on the Cape Wind Energy Project. Several studies have evaluated the public's willingness to pay for larger bird populations (see Appendix B).

property values.[23] This is particularly true of wind power, which will take up greater visual space than the above-water portions of wave and ocean current energy infrastructure. Transformers and any onshore facilities connected to offshore generation may also impact view quality. However, any loss in value due to visual disamenities may be partially counterbalanced by the benefits experienced by some individuals who may enjoy the sight of offshore wind turbines (the only offshore projects easily visible from shore) for aesthetic or symbolic reasons (e.g., perception of "green" power, perception of enhanced energy security). At this point, few studies exist that attempt to quantify or monetize the visual impacts of offshore technologies.[24]

- Effects on tourism and recreation (uncertain effect). The effect of offshore energy facilities on tourism and recreation is uncertain; either may be enhanced or adversely affected depending on the socioeconomic characteristics of the site. Though the effect of disamenities on tourism and recreating is frequently assessed (and monetized), site-specific analysis will likely be required to determine the magnitude of positive or negative impacts associated with the presence of offshore alternative energy facilities.

- Erosional effects on shoals (cost). Disturbances in current and wave patterns due to the presence of offshore wind, wave, or current facilities may alter shoal structure, possibly altering shipping channels and introducing the need for additional dredging. Although the economic impacts of coastal erosion have been studied, it is not expected that facilities sited on the OCS will modify near-shore current and wave patterns.

- Increased recreational fishing (benefit). Fish populations may concentrate in the vicinity of offshore energy facilities, improving localized recreational fishing opportunities. Although the magnitude of this benefit associated with offshore facilities has been neither quantified nor monetized, several studies have monetized the recreational benefits of fishing in other contexts.

#### 3.3.3.3 National/Energy Security Externalities

Development of offshore wind, wave, and current power would contribute to U.S. energy independence, and contribute to a greater sense of national security. Benefits to national security are not readily quantifiable or monetizable.[25]

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[23] As noted in Table 3-6, the visual impacts will be observed during the O&M phase, where costs are incurred over a much longer period than during construction.

[24] Monetization of these impacts could be patterned after a fairly rich literature that has applied hedonic methods to residential property data to value view quality. Given sufficient data on the characteristics that define the value of residential properties in a region, hedonic analysis can be used to assign values to each characteristic of the houses (such as size of yard, number of rooms, or view). Several examples of these studies are included in Appendix B.

[25] For more information on the benefits of energy independence, see: Koplow, D. and A. Martin. 1998. Shifting Accident, Closure and/or Post-Closure Liabilities to the Public Sector, in Fueling Global Warming: Federal Subsidies to Oil in the United States. Prepared for Greenpeace. Accessed on December 8, 2006 from Hhttp://www.earthtrack.net/earthtrack/library/GP%20Ch5_Liability.pdfH

### 3.3.4 Onshore Wind

Offshore alternative energy projects are likely to be in direct competition for investment with other alternative energy sources; the most likely, due to similarity of development scale, is onshore wind power. It is reasonable to assume that the externalities of electricity generated by onshore wind projects will be similar to those identified in Section 3.3.3. The externalities most likely to differ between the generation of electricity from onshore and offshore wind include:

- Avian impacts. Depending on site-specific species population densities and the value placed on preservation of those species, this cost may vary considerably between onshore and offshore projects, but is ultimately dependent on the characteristics of the offshore or onshore facility location.
- Noise impacts. Operational noise, and its potential impact on marine organisms, is one of the potential environmental impacts of offshore energy facilities. This impact is not generally associated with onshore wind turbines. However, noise is an externality with respect to human receptors in the onshore, but generally not the offshore, environment.
- Visibility. Offshore wind turbines sited on the OCS will typically be a minimum of three nautical miles from the nearest human populations; onshore wind turbines may be located nearer populations, but are often sited in more geographically remote regions (i.e., with lower population density). The effect of these two counterbalancing factors on the magnitude of visibility impacts will depend on where the facility is located.

### 3.3.5 Conventional Hydropower

The positive and negative externalities associated with conventional hydropower focus largely on impacts to natural and socioeconomic systems resulting from dramatic changes to the landscape following the impoundment of water behind a dam (or diversion of water to a power project), instream flow modification, and fish habitat modification. Table 3-7 summarizes our judgment regarding the current ability to quantify or monetize relevant benefits and costs associated with conventional hydropower-based electricity generation.

#### 3.3.5.1 Environmental Externalities

The environmental impacts of damming rivers are well documented. Dams and their associated reservoirs and infrastructure alter the physical environment in a lasting and significant way.

- Turbine blades and the inability to migrate upstream past dams (depending on the availability and quality of a fish ladder) disrupt and affect migratory fish populations.

- Dam construction results in diminished or lost habitat for a variety of aquatic and terrestrial species through inundation, modification of upstream and downstream geomorphology, diminished river flows, and increased water temperatures. At the same time, some environmental benefit might be associated with damming a river, as certain fish species thrive under slack water conditions.

## Table 3-7

## Life-Cycle Benefits and Costs Associated with Conventional Hydropower-Based Electricity Generation

| **BENEFIT OR COST**<br>□ Not Applicable<br>░ Not readily quantifiable<br>▒ Not monetizable using readily available data<br>■ Monetizable, at least in part, using readily available data | **LIFE CYCLE PHASE** | | | |
|---|---|---|---|---|
| | **CONSTRUCTION** | **FUEL ACQUISITION & TRANSPORTATION** | **OPERATIONS & MAINTENANCE** | **WASTE & DECOMMISSIONING** |
| **ENVIRONMENTAL** | | | | |
| Net diminishment or impairment of habitat and ecosystems due to footprint of generating facility | ▒ | | ▒ | ▒ |
| Degradation of ecosystems associated with non-greenhouse gas emissions | | | | |
| Degradation of ecosystem associated with waste production (chemical or thermal) | | | | |
| Ecosystem degradation associated with fuel extraction | | | | |
| Net degradation of ecosystems associated with greenhouse gas emissions | | | | |
| **SOCIOECONOMIC** | | | | |
| Net decrease in economic activity associated with non-greenhouse gas emissions | | | | |
| Net effect on visibility and aesthetic factors | | | | |
| Net decline in tourism or recreation opportunities | | | ■ | |
| Loss or degradation of cultural resources | ▒ | | | |
| Economic impacts of greenhouse gas emissions | | | | |
| Water supply security and flood control | | | ■ | |
| **NATIONAL/ENERGY SECURITY** | | | | |
| Possible target for acts of terrorism | | | ░ | |
| Energy independence | | | ░ | |
| **HUMAN HEALTH** | | | | |
| Increased human health risks associated with non-greenhouse gas emissions | | | | |
| Human health risk of potentially catastrophic events | | | ▒ | |
| Human health risk from potential releases of hazardous materials | | | | ▒ |
| Human health risks associated with greenhouse gas emissions | | | | |

- During the decommissioning phase, volumes of sediment laden with heavy metals and other toxic compounds may be released, further affecting downstream habitat.

#### 3.3.5.2 Socioeconomic Externalities

The net external socioeconomic costs associated with conventional hydropower are largely attributable to the damming of rivers and subsequent formation of reservoirs.

- Net changes in recreational resources will result from costs associated with inundated land or changed flow regimes, but benefits will result from increased recreational opportunities at the reservoir. Several studies have been conducted to monetize these changes.[26]

- The potential exists that cultural resources could be submerged during the construction phase of the conventional hydropower lifecycle. As described above, cultural resources could conceivably be quantified but would not be readily monetizable.

There may be substantial external socioeconomic benefits associated with the establishment of a reservoir:

- A benefit of conventional hydropower can be the provision of water supply security to local municipalities and agriculture, making water either a critical input to a profit-seeking business (in the case of agriculture) or an input to a municipality whose residents are willing to pay to avoid droughts. In either case, the water security benefit of the dam can be monetized.

- Dam construction can provide flood control benefits. Reducing the likelihood of flooding has real economic benefits that can be monetized based on downstream property values and increased opportunities for agricultural or municipal development.

#### 3.3.5.3 National/Energy Security Externalities

As potential targets for acts of terrorism, hydroelectric dams present unquantifiable costs in terms of diminished national security. The damage resulting from failure of a conventional hydroelectric facility could be severe in terms of lives lost and electricity supply disruption. At the same time, similar to offshore alternative energy, a real but (for benefit cost analysis purposes) not readily quantifiable benefit of conventional hydropower is its contribution to U.S. energy independence.

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[26] For example, recreational benefits of Georgia's Lake Lanier were monetized in McMahon, G.F., W.W. Wade, B. Roach, M.C. Farmer, and A.J. Friedrich. 2004. Lake Lanier National Economic Development Update: Evaluation of Water Supply, Hydropower, and Recreation Benefits, prepared for the Atlanta Regional Commission. February.

#### 3.3.5.4 Human Health Externalities

Risks to human health associated with conventional hydropower generation are caused by potential dam failure during operation, which is a highly unlikely but potentially devastating possibility, and by potential releases of heavy metals and other toxins during decommissioning.[27] Neither of these risks can be readily quantified or monetized.

## 4.0 BENEFIT-COST ANALYSIS

This chapter combines information presented in earlier chapters with monetary estimates of externalities associated with electricity generation to present a partial, social welfare-based benefit-cost analysis of the representative wind, wave, and ocean current projects. Our analysis focuses on benefits associated with electricity generation using offshore alternative energy resources. Specifically, we present information on benefits defined as the avoided costs that might be associated with alternative, onshore generation.[28] We believe the monetary data available to us capture the most significant externality categories in terms of magnitude and presumed interest to the general public (e.g., the health effects and potential climate change impacts associated with the combustion of fossil fuel for electricity generation). While potential negative externalities (i.e., costs) of offshore alternative energy are easily identifiable (see Chapter 3), data with which to quantify these costs are not readily available.

This chapter is presented in three sections. In the first section we review the literature on the monetization of externalities associated with electricity generation. In the second section we describe how we combined multiple sources of externality valuation data to create a single set of values (expressed in mills per kWh)[29] for specific categories of impacts. In the third section we apply these values to the representative offshore wind, wave, and ocean current projects.

### 4.1 Externality Monetization Literature

In the electricity generation context, the externality monetization literature focuses on fossil fuels and conventional hydropower, largely because of the magnitude and visibility of the external costs associated with these generation modes. A few studies present broad comparisons across energy sources and externality categories. These broader studies are of greatest relevance to our analysis because they provide a uniform basis for examining some of the benefits (i.e., the avoided costs) of offshore alternative energy compared to onshore alternatives. A separate body of literature addresses the potential economic impacts of greenhouse gas emissions and associated climate change impacts.

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[27] For example, the upper reservoir of the Taum Sauk pumped hydro project in southeastern Missouri suffered a catastrophic failure in December of 2005, releasing one billion gallons of water that flowed rapidly through a popular state park. The occurrence of this event during the off season was the primary reason there were not a large number of injuries or fatalities.

[28] As noted in Chapter 3, if data were readily available to do so, it would also be appropriate to evaluate the benefits and costs of offshore renewable energy relative to a conservation alternative.

[29] One mill is equal to one-tenth of one cent, or $0.001.

Many studies have evaluated the general or project-specific impacts of alternative energy (particularly wind power projects; see Appendix A for a partial list of existing studies), but few have attempted to monetize these externalities. In fact, only the New York and ExternE externality studies (described below) include values related to alternative energy that we would consider potentially useful. The New York study only includes costs associated with aesthetic impacts of onshore wind, while ExternE evaluates onshore wind-related noise, morbidity, and occupational health and safety impacts.

Below we describe the four available primary studies that have addressed electricity generation externalities, as well as recent literature that attempts to monetize the effects of climate change.

### 4.1.2 Oak Ridge National Laboratory (ORNL)

Between 1992 and 1998 the Oak Ridge National Laboratory (ORNL), a research arm of the U.S. Department of Energy, and Resources for the Future (RFF) published a series of reports that monetize the externalities associated with electricity fuel cycles, including the extraction, transport, and combustion of fuel used to generate electricity (Lee et al 1995). The ORNL research provides estimates of the monetary value per kWh of externalities associated with five electricity fuel cycles: coal, natural gas, nuclear, biomass, and conventional hydropower. Specifically, these analyses monetize the impacts of each electricity fuel cycle on morbidity, mortality, occupational safety, visibility, agriculture, water quality, and recreation.

ORNL presents externality estimates for reference sites in Roane County in eastern Tennessee and San Juan County in northern New Mexico. The Tennessee estimates are generally higher due to higher population densities and more prevalent crop agriculture in Tennessee compared to New Mexico. The two reference locations provide the principal basis for the presentation of low and high estimates in the ORNL study. All future externalities presented in the study are discounted at five percent.

The ORNL research employs an impact pathway approach to monetize externalities. In general terms, the methodology involves first identifying the quantity of a pollutant emitted at each stage of the electricity fuel cycle. Dispersion models predict the transport of the pollutant throughout the geographic area under study. Dose-response functions are then applied to quantify the effect of increased pollutant concentrations on final variables, such as human health, crop harvests, and visibility. For example, a dose-response function expresses the relationship between changes in emissions concentrations and changes in the annual number of asthma cases.

After estimating the magnitude of impacts on the outcome variables, the ORNL study assigns economic values to these impacts. The method of valuation is specific to the externality under analysis. For example, the costs of increases in morbidity and mortality are derived by summing the costs of treatment and the wages forgone due to illness and shortened life expectancy. Reductions in agricultural harvests are valued at the market price of the crop. ORNL also examine the large body of economics research that uses survey techniques and variation in property values to price public goods such as visibility and recreation. Using the literature they derive average values for incremental changes in the quality of visibility and recreation.

### 4.1.3 New York State Environmental Externalities Cost Study

In 1995, under contract to the Empire State Electric Energy Research Corporation and New York State Energy Research and Development Authority, RCG/Hagler Bailly, Inc. completed a study monetizing the externalities of new and relicensed power plants in New York State (Rowe et al. 1995). The study monetizes impacts on morbidity, mortality, visibility, agriculture, recreational fishing, property values, and buildings and monuments. As with the ORNL study, the scope of the New York study encompasses impacts generated throughout the entire electricity fuel cycle.

This effort involved development of a computer model capable of analyzing the externalities of the following electricity fuel cycles: coal, oil, natural gas, nuclear, municipal solid waste, biomass, conventional hydroelectric, wind, solar, and demand-side management (i.e., conservation). The model is able to analyze each fuel cycle in three distinct geographic settings: an urban location at John F. Kennedy International Airport in New York City, a suburban location in Albany, NY, and a rural location in western New York. This effort used the same impact pathway approach used in the ORNL study and generated low and high values, by fuel type, for each externality, with the low and high values reflecting the differing population density characteristics of the reference sites. As with the ORNL estimates, all future impacts are discounted at five percent.

### 4.1.4 ExternE

The European Commission launched the ExternE project in 1991, with support from the U.S. Department of Energy, as an ongoing effort to monetize the externalities of electricity generation throughout Europe. ExternE researchers have completed externality estimates for twelve different forms of electricity generation. The externality estimates are specific to 15 different countries in the European Union, and encompass impacts on morbidity, mortality, occupational safety, agriculture, forests, fisheries, buildings and monuments, and noise pollution. Like the Oak Ridge and New York studies, ExternE considers damages incurred throughout the electricity fuel cycle and relies on the impact pathway approach to generate low and high values for each externality (again, based primarily on differing population density characteristics of alternative reference locations).

Despite broadly sharing the ORNL and RCG/Hagler Bailly methodology, the ExternE estimates are uniformly higher. These higher estimates are attributable at least in part to the use of a three percent, rather than a five percent, discount rate for future impacts.

### 4.1.5 Triangle Economic Research (TER)

In 1995, under contract to the Northern States Power Company, Triangle Economic Research (TER) published a study estimating the externalities of electricity generation in Minnesota, western Wisconsin, and southeastern South Dakota (TER 1995). The TER study employs the same impact pathway approach common to the ORNL and RCG/Hagler Bailly studies described above in order to estimate impacts on health, agriculture, visibility, and buildings and monuments. However, TER only analyzes externalities from electricity generation. They do not analyze externalities produced during other phases of the electricity fuel cycle, such as fuel extraction and transport, nor do they examine fuels other than natural gas and coal combustion.

### 4.1.6 Valuation of Climate Change Impacts

Arguably most significant externality excluded from the earlier studies is the potential monetary impact of climate change due to the production of carbon dioxide and other greenhouse gases. Uncertainty and complexity have stymied past attempts to monetize these damages accurately and comprehensively (although ExternE did attempt to place a value on climate change, the estimates were based on early data that have since been updated by more recent research). In the past several years, however, researchers have developed models that integrate economic and physical systems to develop per ton estimates of the external costs of carbon emissions. In 1996, the Intergovernmental Panel on Climate Change (IPCC) published one of the first comprehensive reviews of the first generation of these models, which suggested a range of $5 to $125 per metric ton of carbon (Pearce et al. 1996). Clarkson and Dyes (2002) published a review of nine major studies, and recommended a value of $105 per metric ton. Pearce (2003) extended this review, arriving at an estimated range of $6 to $40 per ton of carbon (lower due to incorporation of adaptive management). One of the most widely recognized researchers in this field is Dr. Richard Tol, whose Climate Framework for Uncertainty, Negotiation and Distribution (FUND) models are widely used to study the economic impacts of climate change. Tol estimates a range of $2 to $50 per metric ton of carbon based on his own research and a review of the literature (Guo et al. 2006; Tol 2005).

While we depend on some of these studies to develop monetary estimates of key externalities, we also recognize the limitations of applying monetary values from these studies directly to the analysis of offshore alternative energy benefits and costs. Analytic methodologies continue to evolve, as evidenced by the continuing refinement of the most recent study (ExternE). Nevertheless, we believe they are sufficiently robust for the purpose of this analysis, which is meant to inform future efforts to calculate net benefits. Chapter 5 presents a discussion of the limitations associated with the data we apply in the following sections.

## 4.2 Monetization Data Applied to This Analysis

We reviewed the available externality valuation data to identify unit measures (i.e., dollar per kWh) that we can apply to the representative projects in order to illustrate the monetization of benefits and costs associated with offshore alternative energy. Of the four studies we reviewed, the ExternE study provides the most complete and recent estimates of monetized externalities; however, given its focus on Europe, we are hesitant to transfer the ExternE results to our analysis. Further research could help determine whether, and if so with what adjustments, this data might be applied in a U.S. context. The TER data are also of limited value in the context of our analysis because, given the structure of their results, it is not feasible to express the model results in dollar per kWh units. In addition, the TER study does not address externalities throughout the electricity generation lifecycle. For this analysis, therefore, we focus on the ORNL and New York studies, plus the separate climate change data, and consolidate the relevant results into a single data set.

The ORNL and New York studies present low, central and high estimates of monetized externalities for each reference site they analyze: eastern Tennessee and northern New Mexico in the ORNL study and three New York locations in the New York study (a rural location, Albany, NY and New York City). The eastern Tennessee estimates are generally higher than the northern

New Mexico estimates, primarily due to higher population density in the eastern U.S. compared to the Southwest; likewise, the New York City estimates are generally higher than the rural New York estimates with the Albany estimates lying in between. For the purposes of this analysis, we use the central estimates from each reference site.

Each study also presents independent sets of nearly 30 externality categories (e.g., lead exposure, chronic bronchitis, increased cancer mortality, visibility impairment, and yield reductions for specific crop varieties). To facilitate comparisons between the two studies, we combine some of their central results into broader externality categories, aggregating:

- Health impacts resulting in death in the mortality category;
- Health impacts resulting in sickness, but not death, in the morbidity category;
- Health impacts suffered in the workplace, regardless of whether or not they result in death, in the occupational safety category;
- Water quality impacts not ascribed to human health outcomes in the aquatic impacts category; and
- Impacts to buildings and structures as a result of air pollution in the materials damage category.

Table 4-1 maps these categories, in addition to those that did not require any aggregation, to the general categories in our benefit-cost taxonomy.

Consolidation of the ORNL and New York data involved the following steps:

- For externalities described in one study but not the other, the low and high values were included in the consolidated data.
- For externalities described in both studies, the lower of the two low values and higher of the two high values were included in the consolidated data.

We used this approach to present the widest possible range of values. Averaging or otherwise combining values from the two studies would obscure the differing methods, parameters, and assumptions used to generate each data set.

Table 4-1

Mapping Of Benefit-Cost Taxonomy To Externality Study Categories

| **Benefit or Cost Category** | **Externality Study Damage Category** |
|---|---|
| Human health | Mortality |
| | Morbidity |
| | Occupational Health/Safety |
| | Catastrophic event |
| Environmental | Aquatic Impacts |
| Socioeconomic | Agriculture |
| | Visibility |
| | Recreation |
| | Aesthetics/Property Value/Noise |
| | Materials Damage |
| National/Energy Security | (Not addressed) |

Finally, we incorporate climate change-related data into the consolidated data set by converting dollar per ton estimates (Table 4-2) into dollar per kWh values. We start with the Guo et al. (2006) estimate of $2 to $50 per ton of carbon, since it incorporates the results of previous studies. To convert from dollars per ton to dollars per kWh, we multiply the low and high estimates by a ton per kWh value for each fuel type. Estimation of the ton per kWh values is based on recent EIA data describing total electricity production and carbon emissions by fuel (Table 4-3). Table 4-4 presents the resulting estimated values for the climate change externality (in mills per kWh).

Table 4-5 presents the consolidated data set (non-climate change and climate change externalities).

## Table 4-2

## Estimates of the External Cost of Carbon

| **Literature Source** | **Cost Estimate ($/Ton Carbon)** | |
|---|---|---|
| | Low | High |
| Guo et al. 2006 | $2.00 | $50.00 |
| Pearce et al. 2003 | $4.50 | $40.00 |
| Clarkson and Deyes 2002 | $52.00 | $210.00 |
| Pearce et al. 1996 | $5.00 | $125.00 |

## Table 4-3

## Carbon Production Per Kilowatt Hour (2004)

| **Fuel Type** | **Electricity Generation (Thousand MWH)** | **Carbon Production (Million Tons)** | **Carbon (Tons) Per KWH** |
|---|---|---|---|
| Coal | 1,978,620 | 572.67 | 0.0002894 |
| Petroleum | 120,646 | 29.49 | 0.0002444 |
| Natural Gas | 708,979 | 89.11 | 0.0001257 |

Source: EIA. Electricity page and Environment page. Accessed on January 13, 2006 from http://www.eia.doe.gov/fuelelectric.html and http://www.eia.doe.gov/environment.html. Note that carbon production data presented here was originally presented in metric tons. There are 1.103 short tons (the units presented in this table) in one metric ton.

Table 4-4

External Costs of Carbon Production Per Kilowatt-Hour

| **Fuel Type** | **Externality Estimate (Mills Per kWh)** | |
|---|---|---|
| | Low | High |
| Coal | 0.58 | 14.47 |
| Petroleum | 0.49 | 12.22 |
| Natural Gas | 0.25 | 6.28 |

Table 4-5

Consolidated Externality Values (2006 Mills Per Kilowatt-Hour)

| **Damage Category** | **Natural Gas** | | **Oil** | | **Coal** | | **Nuclear** | | **Conventional Hydro** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Low** | **High** | **Low** | **High** | **Low** | **High** | **Low** | **High** | **Low** | **High** |
| **HUMAN HEALTH** | | | | | | | | | | |
| Mortality | 0.003 | 1.484 | 0.996 | 3.481 | 0.132 | 3.088 | 0.031 | 0.112 | - | - |
| Morbidity | 0.003 | 0.718 | 0.801 | 4.071 | 0.074 | 1.902 | 0.000 | 0.006 | - | - |
| Occupational Health/Safety | - | - | - | - | 0.061 | 0.635 | 0.169 | 0.169 | - | - |
| Catastrophic event | - | - | - | - | - | - | 0.022 | 0.272 | - | - |
| **ENVIRONMENTAL** | | | | | | | | | | |
| Aquatic Impacts | - | - | - | - | 0.004 | 0.005 | - | - | - | - |
| **SOCIOECONOMIC** | | | | | | | | | | |
| Agriculture | 0.000 | 0.099 | 0.000 | 0.003 | 0.000 | 0.197 | - | - | - | - |
| Visibility | 0.007 | 0.030 | 0.049 | 0.091 | 0.184 | 0.236 | - | - | - | - |
| Recreation | - | - | 0.007 | 0.022 | 0.053 | 0.122 | - | - | 0.000 | 0.160 |
| Aesthetics/Property Value/Noise | 0.014 | 0.049 | 0.102 | 0.283 | 0.022 | 0.092 | 0.017 | 0.187 | 0.000 | 0.062 |
| Materials Damage | 0.007 | 0.081 | 0.037 | 0.276 | 0.081 | 0.718 | - | - | - | - |
| SUBTOTAL | 0.035 | 2.460 | 1.993 | 8.226 | 0.611 | 6.996 | 0.239 | 0.746 | 0.000 | 0.222 |
| **CLIMATE CHANGE** | | | | | | | | | | |
| Climate change | 0.251 | 6.284 | 0.489 | 12.220 | 0.579 | 14.471 | - | - | - | - |
| **GRAND TOTAL** | **0.286** | **8.744** | **2.482** | **20.447** | **1.189** | **21.467** | **0.239** | **0.746** | **0.000** | **0.222** |

## 4.3 Benefit-Cost Analysis

This section applies the externality values presented above to the representative projects described in Chapter 2. Specifically, for each project we calculated the externality costs associated with an equivalent amount of onshore electricity generation that might be displaced by the offshore project. These monetized costs can be considered "avoided cost" benefits of the offshore project. It is important to note, however, that this represents only one piece of what would be a complete benefit-cost analysis, since available information does not enable us to consider the full range of likely benefits, and, more importantly, does not allow us to estimate, in monetary terms, the social costs associated with the offshore projects (e.g., impacts on marine life).

For each representative project we considered two displacement scenarios. The first is intended to illustrate displacement of a "high" externality fuel. Table 4-5 suggests that oil-fired generation results in the greatest lifecycle externalities. However, since oil-fired power plants account for a small percentage of electricity generation in the U.S., we use the values associated with coal-fired generation instead. Recognizing that offshore alternative energy might not displace what is often baseload, coal-fired generation and, as noted previously, that a precise determination of what would be displaced is beyond the scope of this analysis, we include for illustrative purposes a second scenario in which displacement is based on a proportional mix of the fuels that serve the region into which the offshore project would supply electricity. The basis for these regional mixes is the EIA data presented in Chapter 2. We re-weighted the shares by removing electricity generation from geothermal resources, municipal solid waste, and wood and other biomass, as appropriate, since these are not otherwise addressed in our analysis (Table 4-6). We then calculated weighted average externality values by region by multiplying each low and high, fuel-specific value from Table 4-5 by the corresponding fuel type share. Table 4-7 presents the per-kWh externality values for the two scenarios.

Table 4-6

Re-Weighted Regional Electricity Generation Mixes

| **Fuel Type** | **Share of Electricity Generation** | | |
|---|---|---|---|
| | Mid-Atlantic | Northwest | Florida |
| Natural Gas | 8.39% | 9.31% | 36.51% |
| Petroleum | 2.64% | 0.42% | 12.61% |
| Coal | 49.95% | 31.05% | 36.61% |
| Nuclear | 37.32% | 3.34% | 14.25% |
| Conventional Hydro | 1.59% | 55.86% | 0.01% |
| Wind | 0.10% | 0.01% | 0.00% |
| **Total** | **100.00%** | **100.00%** | **100.00%** |

Table 4-7

Externality Values in Mills Per Kilowatt Hour, by Scenario

| **Damage Category** | **Scenario 1** | | **Scenario 2** | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Coal | | Mid-Atlantic | | Northwest | | Florida | |
| | Low | High | Low | High | Low | High | Low | High |
| **HUMAN HEALTH** | | | | | | | | |
| Mortality | 0.132 | 3.088 | 0.104 | 1.801 | 0.046 | 1.115 | 0.179 | 2.127 |
| Morbidity | 0.074 | 1.902 | 0.059 | 1.120 | 0.027 | 0.675 | 0.130 | 1.473 |
| Occupational Health/Safety | 0.061 | 0.635 | 0.094 | 0.380 | 0.025 | 0.203 | 0.046 | 0.257 |
| Catastrophic event | - | - | 0.008 | 0.101 | 0.001 | 0.009 | 0.003 | 0.039 |
| **ENVIRONMENTAL** | | | | | | | | |
| Aquatic Impacts | 0.004 | 0.005 | 0.002 | 0.003 | 0.001 | 0.002 | 0.002 | 0.002 |
| **SOCIOECONOMIC** | | | | | | | | |
| Agriculture | 0.000 | 0.197 | 0.000 | 0.107 | 0.000 | 0.070 | 0.000 | 0.108 |
| Visibility | 0.184 | 0.236 | 0.094 | 0.123 | 0.058 | 0.076 | 0.076 | 0.109 |
| Recreation | 0.053 | 0.122 | 0.027 | 0.064 | 0.017 | 0.127 | 0.020 | 0.048 |
| Aesthetics/Property Value/Noise | 0.022 | 0.092 | 0.021 | 0.128 | 0.009 | 0.075 | 0.029 | 0.114 |
| Materials Damage | 0.081 | 0.718 | 0.042 | 0.373 | 0.026 | 0.232 | 0.037 | 0.327 |
| SUBTOTAL | 0.611 | 6.996 | 0.450 | 4.201 | 0.209 | 2.585 | 0.522 | 4.603 |
| **CLIMATE CHANGE** | | | | | | | | |
| Climate change | 0.579 | 14.471 | 0.323 | 8.080 | 0.205 | 5.130 | 0.365 | 9.134 |
| **GRAND TOTAL** | **1.189** | **21.467** | **0.773** | **12.280** | **0.415** | **7.716** | **0.887** | **13.737** |

Table 4-8 summarizes the key characteristics of the three representative projects (annual electricity generation and projected operating lifetime). For each project, we assume constant annual generation across the project lifetime. Annual externalities under the two scenarios are the product of annual generation and the appropriate values from the "Subtotal" row (for the "without climate change" results) and from the "Grand Total" row (for the "with climate change results) of Table 4-7. Table 4-9 presents these results, rounded to three significant digits. As a final step, we assume the annual results in Table 4-9 will remain constant over the anticipated operating lifetime of each project, beginning in the assumed first year of operation, and then discount each series of annual totals to current (2007) dollars using a five percent discount rate.[30] These calculations result in total, present value estimates of the monetized externalities associated with each project (see Tables 4-10, 4-11, and 4-12).

It is important to note that these results should not be viewed as indicative of the estimated net benefits of the representative offshore alternative energy projects, since we are unable to monetize, using readily available information, the social costs that might be associated with these projects.

Table 4-8

Key Characteristics of Representative Offshore Projects

| **Project Type** | **Location** | **Annual Electricity Production (Mwh)** | **1st Year Of Operation** | **Expected Life (Years)** |
|---|---|---|---|---|
| Wind | Mid-Atlantic | 1,100,000 | 2010 | 25 |
| Wave | Pacific Northwest | 300,000 | 2012 | 20 |
| Current | Florida Gulf Stream | 140,000 | 2014 | 20 |

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[30] We chose a discount rate of five percent to maintain consistency with the discount rates used in the ORNL and New York externality studies.

Table 4-9

Summary of Estimated Annual Externalities (Partial Benefits/Avoided Costs Only)

| **Generation Type** | **Displaced Fuel** | **Without Climate** | | **With Climate** | |
|---|---|---|---|---|---|
| | | Low | High | Low | High |
| Wind | Coal | $670,000 | $7,700,000 | $1,310,000 | $23,610,000 |
| | Regional mix | $495,000 | $4,620,000 | $850,000 | $13,510,000 |
| Wave | Coal | $183,000 | $2,100,000 | $357,000 | $6,440,000 |
| | Regional mix | $63,000 | $776,000 | $124,000 | $2,315,000 |
| Current | Coal | $85,000 | $979,000 | $167,000 | $3,005,000 |
| | Regional mix | $73,000 | $644,000 | $124,000 | $1,923,000 |

### 4.3.1 Offshore Wind Energy Example

Table 4-10 presents the estimated partial benefits (avoided costs) associated with the representative offshore wind energy project over its presumed 25-year lifetime. Based on our externality values, this project might be expected to offset externalities ranging from approximately $17 million to $302 million over 25 years, including the potential social benefits associated with avoided greenhouse gas emissions, if it were to displace coal-fired generation. If we assume displacement of a regional (i.e., Mid-Atlantic) fuel mix, the results are between approximately $11 million and $173 million, the decrease resulting largely due to the relatively high dependence in this region on electricity generation that does not produce greenhouse gases during its operational phase (nuclear energy, 37 percent). Note that a significant percentage of the calculated benefits in both scenarios is associated with avoided greenhouse gas emissions (approximately one-third at the low end and approximately three-quarters at the high end). Among the non-greenhouse gas-related externalities, occupational health and safety is most significant at the low end, while human health mortality dominates at the high end.

Table 4-10

Discounted Present Value of the Partial Benefits (Avoided Costs) Associated with the Representative Wind Energy Project

| **Displaced Fuel** | **Without Climate** | | **With Climate** | |
|---|---|---|---|---|
| | Low | High | Low | High |
| Coal | $8,600,000 | $98,400,000 | $16,700,000 | $302,000,000 |
| Regional mix | $6,300,000 | $59,100,000 | $10,900,000 | $173,000,000 |

### 4.3.2 Offshore Wave Energy Example

Table 4-11 presents the estimated partial benefits (avoided costs) associated with the representative offshore wave energy project over its presumed 20-year lifetime. Based on our externality values, this project might be expected to offset externalities ranging from approximately $4 million to $66 million over 20 years, including the potential social benefits associated with avoided greenhouse gas emissions, if it were to displace coal-fired generation. If we assume displacement of a regional (i.e., Northwest) fuel mix, the results are between approximately $1 million and $24 million. In this case the decrease is a result of that region's dependence on low-externality conventional hydropower for more than half its electricity. Again, the largest share of the externalities in both scenarios is associated with avoided greenhouse gas emissions, with avoided occupational health risks (at the low end) and avoided human mortality (at the high end) dominant among the other externalities. The absolute magnitude of the externalities relative to the wind example are smaller due to the assumption that the annual generation from the representative wave energy project is less than one-third that of the representative wind energy project.

Table 4-11

Discounted Present Value of the Partial Benefits (Avoided Costs) Associated with the Representative Wave Energy Project

| **Displaced Fuel** | **Without Climate** | | **With Climate** | |
|---|---|---|---|---|
| | Low | High | Low | High |
| Coal | $1,880,000 | $21,500,000 | $3,660,000 | $66,000,000 |
| Regional Mix | $640,000 | $7,950,000 | $1,270,000 | $23,700,000 |

### 4.3.3 Offshore Ocean Current Energy Example

Table 4-12 presents the estimated partial benefits (avoided costs) associated with the representative offshore ocean current energy project over its presumed 20-year lifetime. Based on our externality values, this project might be expected to offset externalities ranging from approximately $2 million to $28 million over 20 years, including the potential social benefits associated with avoided greenhouse gas emissions, if it were to displace coal-fired generation. If we assume displacement of the regional (i.e., Florida) fuel mix, the results are between approximately $1 million and $18 million. A relatively large contribution from natural gas (37 percent) and nuclear power (14 percent) contribute to these lower values. Here too the largest share of the externalities in both scenarios is associated with avoided greenhouse gas emissions, with avoided occupational health risks (at the low end) and avoided human mortality (at the high end) dominant among the other externalities. The absolute magnitude of the externalities in this case are also smaller due to the smaller assumed scale of the representative ocean current energy project.

Table 4-12

Discounted Present Value of the Partial Benefits (Avoided Costs) Associated with the Representative Ocean Current Energy Project

| **Displaced Fuel** | **Without Climate** | | **With Climate** | |
|---|---|---|---|---|
| | Low | High | Low | High |
| Coal | $790,000 | $9,110,000 | $1,550,000 | $27,900,000 |
| Regional Mix | $679,000 | $5,990,000 | $1,160,000 | $17,900,000 |

## 5.0 DISCUSSION AND RECOMMENDATIONS

The purpose of this document is to inform the future consideration of benefits and costs associated with the use of OCS resources for the generation of wind-, wave-, and ocean current-derived energy. In the preceding chapters we characterized representative wind, wave, and ocean current energy projects, defined a taxonomy of potential benefits and costs that might be associated with the development of such projects, and applied readily available literature on the externalities of electricity generation to present illustrative examples of how these externality estimates can be applied. As a general conclusion, we would suggest that the avoidance of externalities that would otherwise result from onshore, conventional electricity generation is likely the largest category of benefits of offshore alternative energy projects.

This chapter presents a discussion of the limitations of our analysis, as well as recommendations for future work. In general, the limitations and our recommendations address three issues: the inability to calculate net benefits of offshore alternative energy projects due to the lack of monetary estimates of their impact on human and natural environments; the "completeness" of the benefits assessment (i.e., our ability to capture and monetize all of the important categories of externalities); and the sensitivity of reported externality values to certain factors.

### 5.1 Inability to Estimate Net Benefits

Research efforts have not yet produced a reliable body of peer-reviewed monetary estimates of the externalities associated with offshore alternative electricity generation (e.g., the ecological impact of a project's footprint, recreational impacts). Absent such information, we cannot estimate the net benefits of an offshore alternative energy project. Appendix A provides a list of studies we have identified that qualitatively or quantitatively address potential impacts of offshore alternative energy projects.

### 5.2 Non-monetized Benefits

Our assessment of the benefits of offshore generation focus on the avoidance of externalities associated with generation at onshore facilities, such as coal-fired power plants. Readily available information, specifically the externality studies described in Chapter 4, allows us to estimate the monetary value of several of these benefits/avoided costs with respect to representative offshore alternative energy projects. Other potential benefits and costs identified in our taxonomy, particularly those in the categories of environmental and national/energy security impacts, cannot be readily monetized on the basis of existing information. However, we do not believe it is critical to monetize these additional externalities, since the magnitude of non-monetized benefits is unlikely to be significant relative to those that we can monetize (particularly the substantial human health and climate change externalities, which we believe are the most important to capture in a benefit-cost analysis of alternative energy). Qualitative or quantitative (but non-monetary) assessments will be sufficient in many cases. As noted in OMB Circular A-94 (Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs):

> Although net present value is not always computable . . . , efforts to measure it can produce useful insights even when the monetary values of some benefits or costs cannot be determined. In these cases:

1. A comprehensive enumeration of the different types of benefits and costs, monetized or not, can be helpful in identifying the full range of program effects.

2. Quantifying benefits and costs is worthwhile, even when it is not feasible to assign monetary values; physical measurements may be possible and useful. (emphasis in original)

## 5.3 Sensitivity of Externality Values to Methodologies and Inputs

While we believe the ranges of values in Chapter 4 that describe benefits associated with representative offshore alternative energy projects provide a reasonable first approximation, we also recognize that the underlying externality values are highly sensitive to several key methodological and input decisions. Thus, the available literature does not allow us to present a precise measure of benefits. Research and analysis of these studies and externality valuation continues, with continuous refinement of both methodologies and inputs. Krupnick and Burtraw (1996), for example, looked critically at the ORNL, New York, and ExternE studies to examine their credibility as well as their transferability to other benefit assessments. While they conclude that "the degree of consensus around health-related concentration-response and valuation functions, and the relative transferability of such functions, puts the heart of this social costing effort on reasonably solid footing," they also note, for example, that the desire to simplify the computational requirements of these large models leads to an inability to address potential non-linearities in the air quality modeling that is central to these analyses.

In particular, we note three instances in which the choice of a methodology or analytic input has a significant bearing on resulting externality values.

- **Affected population.** When values are derived based on an assessment of the population affected by a particular externality (such as health effects that result from airborne pollutants), the location chosen for modeling the impact will have a significant bearing on the results. In general, the externality values will be higher in more densely populated areas and lower in less densely populated areas. This effect is seen in the range of values associated with the studies described in Chapter 4, each of which developed a range of estimates using less- and more-densely populated reference locations. Considerable differences are observed between studies. For example, in the case of the coal fuel cycle analyses, the affected population at the Albany reference site in the New York study is roughly half the affected population considered for the eastern Tennessee reference site in the ORNL study.

- **Key parameters.** In addition to methodological choices, such as which population to model when assessing a particular externality, analysts must also choose from a range of possible input values for key parameters. For example, with respect to the important externality of human health impacts from airborne emissions, a significant driver of the monetary result will be the value of a statistical human life, a measure that has been the subject of substantial analysis and debate and for which a range of values have been suggested (see for example the discussion of fatality risks in OMB 2003).

- **Discount rate.** A discount rate is used to express future impacts in present value terms Higher discount rates will reduce the present value of externalities, while lower discount rates will increase them. To illustrate the sensitivity of a present value calculation to the choice of discount rate, consider that for a 25-year series of constant annual amounts that begins in the year 2010, switching from a five percent to a three percent discount rate would increase the present value of that series by nearly 30 percent.

## 5.4 Recommendations

Based on our research, and given the above discussion, we offer three recommendations regarding future research to support the assessment of the net benefits of offshore alternative energy projects.

- Support development of reliable estimates of the costs of these projects, with a particular emphasis on the economic valuation of their potential impact on marine ecology.

- Continue to support the qualitative or quantitative assessment of benefits that cannot be monetized on the basis of existing literature. Monetization of these benefits is not likely to be necessary, since the cost of doing so would likely outweigh any improvement in the accuracy of a net benefit assessment.

- Focus additional benefits assessment work on ensuring that benefits measures from existing studies can be reliably transferred to future assessments. In particular, research should be undertaken to: (1) determine what adjustments, if any, would need to be made to allow for the transferability of the ExternE results to assessment of U.S. projects, and (2) refine estimates of climate change externalities by doing thorough analyses of each monetization study in the literature.

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## APPENDIX A STUDIES OF EXTERNALITIES ASSOCIATED WITH OFFSHORE ELECTRICITY GENERATION

### *Bird Mortality/Wildlife Impacts*

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### *Tidal Current Energy Technologies*

Electric Power Research Institute, Inc. 2006. Instream tidal power in North America: Environmental and Permitting Issues, prepared by Devine Tarbell & Associates, Inc. June. Accessed on December 22, 2006 at http://www.epri.com/oceanenergy/attachments/streamenergy/reports/007_Env_and_Reg_Issues_Report_060906.pdf

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### *Wave Technology*

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# APPENDIX B ECONOMIC STUDIES POTENTIALLY RELEVANT TO THE ANALYSIS OF COSTS AND BENEFITS OF ELECTRICITY GENERATION USING OFFSHORE ALTERNATIVE ENERGY RESOURCES

## ***Environmental Externalities***

### *Avian Interactions*

Ahearn, M.C., K.J. Boyle, and D.R. Hellerstein. 2006. Designing a contingent valuation study to estimate the benefit of the conservation reserve program on grassland bird populations. In *Handbook on Contingent Valuation*. A. Alberini and J.R. Kahn, eds. Edward Elgar Publishing. Northampton, MA.

- A contingent valuation study of changes in grassland bird populations.

Boyle, K.J. and R.C. Bishop. 1987. Valuing Wildlife in Benefit-Cost Analyses: A Case Study Involving Endangered Species. *Water Resources Research*. 23(4),pp. 943-950.

- Evaluates the use and non-use values of two endangered species in Wisconsin.

Carson, R.T., R.C. Mitchell, M. Hanemann, R. J. Kopp and S. Presser. 1994. Contingent Valuation and Lost Passive Use: Damages from the Exxon Valdez. University of California at San Diego, Economics Working Paper Series 95-02, Department of Economics, UC San Diego.

- Describes a study of non-use values (including biological services) associated with the Exxon Valdez oil spill.

Kotchen, M.J. and S.D. Reiling. 2000. Environmental attitudes, motivations, and contingent valuation of nonuse values: a case study involving endangered species. Ecological Economics. 32(1), pp. 93-107.

- Investigates the underlying motivations behind contingent valuation responses, and presents the results of a contingent valuation survey for Peregrine Falcons.

Stevens, T.H., J. Echeverria, R.J. Glass, T. Hager and T.A. More. 1991. Measuring the Existence Value of Wildlife: What Do CVM Estimates Really Show? *Land Economics*, 67(4), pp. 390-400.

- Examines valuation approaches for four species introduced or reintroduced to New England: the Bald Eagle, Atlantic Salmon, Wild Turkey, and Coyote.

### *Artificial Reef Effects from Scour Pads or Other Seafloor Interface*

Moberg, F. and C. Folke. 1999. Ecological goods and services of coral reef ecosystems. *Ecological Economics*. 29(2), pp. 215-233.

- Examines some of the benefits and services associated with coral reef ecosystems and describes some of the human impacts on these systems.

Loomis, J.B. and D.S. White. 1996. Economic Values of Increasingly Rare and Endangered Fish. *Fisheries*. 21, pp. 6–10.

- Presents results from recent surveys that have attempted to elicit the economic values the public holds for rare and endangered fish.

Olsen, D.; J. Richards and R.D. Scott. 1991. Existence and sport values for doubling the size of Columbia River basin salmon and steelhead runs. *Rivers.* 2(1), pp. 44-56.

- Summarizes the results of an existence valuation study focused on Steelhead in the Pacific Northwest.

Pendleton, L. 1995. Valuing Coral Reef Protection. *Ocean and Coastal Management.* 26(2), pp. 119-131.

- Develops an economic framework to estimate the benefits associated with avoided reef degradation.

Spash, C.L. 2002. Informing and forming preferences in environmental valuation: Coral reef biodiversity. *Journal of Economic Psychology.* 23(5), pp. 665-687.

- Evaluates the benefits of improving coral reef biodiversity using a contingent valuation model.

## ***<u>Socioeconomic Externalities</u>***

### *Visual Impacts*

Bishop, I. and Miller, D. 2007. Visual assessment of off-shore wind turbines: The influence of distance, contrast, movement and social variables. *Renewable Energy.* 32, pp. 814–831.

- Uses an online survey in an attempt to establish parameters of wind turbine visibility and impact at different distances from viewer, under different lighting conditions.

Chestnut, L.G. and R.D. Rowe. 1990a. *Preservation Values for VisibilityProtection at the National Parks*. Prepared for U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, and National Park Service, Air Quality Management Division.

- Estimates the mean annual willingness to pay to improve visibility conditions from a visual range of 155 kilometers to 200 and 250 kilometers.

Colwell, P.F. 1990. Power Lines and Land Value. *The Journal of Real Estate Research,* pp. 117-127.

- Investigates the effect of power lines and towers on nearby property values.

Paterson, R.W. and K.J. Boyle. Out of Sight, Out of Mind? Using GIS to Incorporate Visibility in Hedonic Property Value Models. *Land Economics* 2002. 78(3), pp. 417-425.

- Examines the effect of visible developments on property values.

Stevens, Thomas H., John M. Halstead, Wendy Harper, Ina Porras, L. Bruce Hill, Theresa L. Walker, and Cleve Willis. 2000. *The Value of Visibility: A Comparison of Stated Preference Methods*. Paper prepared for presentation at U.S. Environmental Protection Agency. Washington, D.C. October 12-13.

- A conjoint ranking and contingent valuation study designed to estimate willingness to pay/accept for visibility improvements/declines in a national forest in New Hampshire.

Tolley, G. and R. Fabian, eds. 1988. The Economic Value of Visibility. Studies in Urban and Resource Economics. The Blackstone Company, Mt. Pleasant, MI.

- Includes a series of chapters that describe the approaches and methodologies for valuing visibility.

### ***Effects on Tourism and Recreation***

Grigalunas, T. A., J. J. Opaluch, D. French, and M. Reed. 1988. Measuring damages to marine natural resources from pollution incidents under CERCLA: Applications of an integrated ocean systems/economic model. *Marine Resources Economics* 5, pp. 1–21.

- Discusses the Natural Resource Damage Assessment Model for Coastal and Marine Environments (NRDAM/CME), which employs a biological/economic model to simulate the impacts associated with oil spills.

Park, T. Bowker, J.M. and Leeworthy, V.R. 2002. Valuing snorkeling visits to the Florida Keys with stated and revealed preference models. *Journal of Environmental Management*. 65, pp. 301-312.

- Develops a travel cost-contingent valuation model of demand for trips to the Florida Keys. Focuses on willingness to pay to preserve the water quality and health of coral reefs.

Parsons, G. R and D.M. Massey. 2003. A Random Utility Model of Beach Recreation, in The New Economics of Outdoor Recreation, eds., N. Hanley, W. D. Shaw, and R.E. Wright, Edward Elgar.

- Develops a random utility model to investigate the value of beach recreation.

### ***Competition with Commercial Fishing***

Blomo, V.J. 1987. Distribution of Economic Impacts from Proposed Conservation Measures in the U.S. Atlantic Menhaden Fishery. *Fisheries Research*. 5, pp. 23-28.

- Uses a bioeconomic model to examine the impacts of proposed conservation regulations in the U.S. Atlantic menhaden fishery.

Cheng, H.-T. and R.E. Townsend. Potential Impact of Seasonal Closures in the U.S. Lobster Fishery. *Marine Resource Economics*. 8, pp. 101-107.

- Investigates the impact of potential seasonal closures on the U.S. lobster fishery.

### *Erosional effects*

Leatherman, S.P. et al. 2000. Evaluation of Erosion Hazards. Prepared by The H. John Heinz III Center for Science, Economics, and the Environment for the Federal Emergency Management Agency (FEMA)

- Examines the economic impacts associated with coastal erosion, focusing primarily on risks to beachfront properties.

### *Increased recreational fishing*

Bockstael, N., A. Graefe, I. Strand, and L. Caldwell. 1986. Economic Analysis of Artificial Reefs: A Pilot Study of Selected Valuation Methodologies. Artificial Reef Development Center, Technical Report Series.

- Estimates welfare effects of artificial reefs in South Carolina from both contingent valuation and recreational demand modeling.

Brander, L.M., P. Van Beukering, H.S.J. Cesar. 2006. The recreational value of coral reefs: A meta-analysis. *Ecological Economics.* doi:10.1016/j.ecolecon.2006.11.002.

- Conducts a meta-analysis on 52 of the 166 coral reef valuation studies the authors identify. The study focuses on recreational values.

Ditton, R.B. and T.L. Baker. 1999. Demographics, attitudes, management preferences, and economic impacts of sportdivers using artificial reefs in offshore Texas waters. Department of Wildlife and Fisheries Societies, Texas A&M University.

- Estimates the total expenditures on diving off artificial reefs in Texas.

## The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

## The Minerals Management Service Mission

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the **Offshore Minerals Management Program** administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS **Minerals Revenue Management** meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

The MMS strives to fulfill its responsibilities through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection.