Partnership for AiR Transportation
Noise and Emissions Reduction
An FAA/NASA/Transport Canada-
sponsored Center of Excellence

Requirements Document for the Aviation Environmental Portfolio Management Tool

prepared by
Ian Waitz, Stephen Lukachko, Yongki Go,
Peter Hollingsworth, Kate Harback, Fred Morser

June 2006

REPORT NO. PARTNER-COE-2006-001

Requirements Document for the Aviation Environmental Portfolio Management Tool

Ian Waitz, Stephen Lukachko, Yongki Go — MIT
Peter Hollingsworth — Georgia Tech
Kate Harback, Fred Morser — MITRE

The authors express their appreciation to the individuals who reviewed drafts of this report, offering their thoughtful comments and expert counsel. Following careful examination, we addressed many of these suggestions in this final version. Other suggestions are being considered as part of ongoing development; we will address these suggestions in future documents. This inclusive process is inherent to PARTNER's mission and philosophy. It greatly contributes to the thoroughness of our research, enhancing accuracy, validity, and communication with a broad-based constituency.

Submitted to:
Maryalice Locke
APMT Program Manager
Office of Environment and Energy
U.S. Federal Aviation Administration
800 Independence Avenue, S.W.
Washington, D.C. 20591
Phone: (202)-267-3495
maryalice.locke@faa.gov

Contact:
Professor Ian A. Waitz, Director
PARTNER
Massachusetts Institute of Technology
77 Massachusetts Avenue 33-207
Cambridge, MA 02139
iaw@mit.edu

Funded under FAA Cooperative Agreement No. 03-C-NE-MIT

Cover photo: Shutterstock

EXECUTIVE SUMMARY

The Federal Aviation Administration's Office of Environment and Energy (FAA-AEE) is developing a comprehensive suite of software tools that will allow for thorough assessment of the environmental effects of aviation. The main goal of the effort is to develop a new capability to assess the interdependencies between aviation-related noise and emissions effects, and to provide comprehensive cost analyses of aviation environmental impacts. The economic analysis function of this suite of software tools has been given the rubric Aviation Environmental Portfolio Management Tool (APMT). This function will ultimately be derived from existing tools, tools currently under development, and new tools that must be developed.

FAA-AEE has provided a grant to the Partnership for AiR Transportation Noise and Emissions Reduction (PARTNER), an FAA/NASA/Transport Canada-sponsored Center of Excellence, to work collaboratively with stakeholders in developing the requirements for environmental economic analysis[1] that will fall within APMT. This report provides a detailed account of these requirements along with supporting background discussions that will help place these requirements within the broader context of current practice.

Current practice within FAA and the International Civil Aviation Organization's Committee on Aviation Environmental Protection (ICAO-CAEP) focuses on cost-effectiveness analysis[2]. APMT must be capable of reproducing these capabilities and then expanding beyond them. The primary environmental impacts that must be addressed are local air quality, community noise, and climate change. Throughout the development of APMT it will be important to balance practicality with thoroughness.

Because of the immediacy of upcoming global decisions and the need to adequately inform these decisions, the highest priority for the geographical and economic scope for all of these analyses should be global and regional (or national). Thereafter, focused studies over smaller geographical areas and economies could be pursued (e.g. within a single airport community).

To respond to the near-term needs, we recommend that the FAA start immediately to develop the capabilities for an expanded cost-effectiveness analysis that would be operational within 1-3 years. The analysis should accept as input a range of environmental performance indicators (e.g. number of people living within DNL 65dB,

---

[1] Throughout this document, as is typical in environmental economic analysis, we will label changes in monetary flows in the aviation markets and the general economy as "costs" although it is recognized that they may be positive or negative. Similarly, we will label changes in health and welfare that occur through environmental pathways as "benefits" although they may be positive or negative.

[2] Cost-Effectiveness Analysis (CEA) is used to determine the outcome or impact of alternative regulatory choices. It is useful for answering the question: "Given several options for addressing an environmental problem through regulation—each (ideally) with similar benefits, which choice has the lowest costs?" Typically the benefits are defined using some surrogate for the ultimate environmental effect (e.g. kg NO_x vs. the value of adverse health effects).

kg NO_x, kg fuel burn, etc.) and enable a first assessment of indirect environmental effects that policy options in one domain may produce in another domain (e.g. the effects of noise stringency on NO_x levels). The FAA should also start immediately to develop the capabilities for benefit-cost analysis[3] within the primary aviation markets. These capabilities should include monetization of benefits and partial equilibrium modeling of the consumers and producers in the primary markets. These tools would supplant the cost-effectiveness analyses that will be relied upon in the near term. Due to limited availability of data, it is expected that this capability will be developed first for application within the U.S. (within 1-3 years) and then expanded internationally through partnerships and collaborations (3-6 years).

To address longer-term needs (3-8 years), future APMT development should focus on expanding these capabilities to include the addition of indirect and induced cost assessments. A general equilibrium model should form the basis of these capabilities, using a resolution that would allow for distributional analyses. As environmental economics research and its application to aviation continue to mature, it will be necessary to include complementary indirect and induced benefits assessment to provide a complete capability for benefit-cost and distributional analyses.

This Requirements Document is the first of a three-document series relating the development of APMT. The second document is an APMT Architecture Study that describes in detail the components of the APMT architecture, outlines the interfaces that will be required among those components, and establishes how APMT will interface with other tools that exist or are under development, including the Environmental Design Space (EDS) and the Aviation Environmental Design Tool (AEDT). The Architecture Study also reviews existing tools available for these types of analyses, assesses their suitability for use in APMT, and establishes the additional development that will be necessary to achieve APMT requirements. The third companion document is an APMT Prototype Work Plan that describes an initial APMT prototyping effort intended to identify gaps or weaknesses in the APMT architecture and stimulate advancements in development. The Prototype Work Plan delineates all of the entities necessary for the analyses, their roles, data requirements, and proposed schedule.

---

[3] Benefit-Cost Analysis (BCA) seeks to determine the extent to which a policy option will produce a net benefit to society (independent of distributional aspects such as who wins and who loses). By estimating the net present value of benefits less costs relative to a well-defined baseline scenario, BCA can be used to determine the degree to which a policy scenario improves economic efficiency. BCA requires that benefits and costs be expressed in the same units (typically monetary). It is the recommended basis in North America and Europe for assessing policy alternatives.

TABLE OF CONTENTS

LIST OF ACRONYMS

ACES	Airspace Concepts Evaluation System
AEDT	Aviation Environmental Design Tool
AERO-MS System	Aviation Emissions and Evaluation of Reduction Options Modeling
AIM	Asia-Pacific Integrated Model
AIP	Airport Capital Improvement Plan
ASD	Office of System Architecture and Investment Analysis
APMT	Aviation Environmental Portfolio Management Tool
APO	Office of Aviation Policy and Plans
ARP	Office of Airports
ATM	Air Traffic Management
ATO	Air Traffic Organization
BCA	Benefit-Cost Analysis
CAEP	Committee on Aviation Environmental Protection
CEA	Cost-Effectiveness Analysis
CEQ	Council on Environmental Quality
CNS	Communications, Navigation, Surveillance
COI	Cost of Illness
CV	Contingent Valuation
DA	Distributional Analysis
DOE	Department of Energy
EDMS	Emissions and Dispersion Modeling System
EDS	Environmental Design Space
EEA	European Environment Agency
EEC	Eurocontrol Experimental Centre
EIA	Economic Impact Analysis
EPA	Environmental Protection Agency
EVRI	Environment Valuation Reference Inventory
FAA	Federal Aviation Administration
FAA-AEE	FAA Office of Environment and Energy

FESG	Forecasting and Economic Analysis Support Group
FICAN	Federal Interagency Committee on Aviation Noise
GDP	Gross Domestic Product
GEM	Global Emissions Model
ICAO	International Civil Aviation Organization
INM	Integrated Noise Model
JPDO	Joint Planning and Development Office
MAGENTA	Model for Assessing Global Exposure to Noise from Transport Aircraft
MAIPA	Multi-Attribute Impact Pathway Analysis
MBO	Market-based Options
NASA	National Aeronautics and Space Administration
NCEE	National Center for Environmental Economics
NDI	Noise Depreciation Index
NEPA	National Environmental Policy Act
NGATS	Next Generation Air Transportation System
NRC	National Research Council
OECD	Organisation for Economic Co-operation and Development
OMB	Office of Management and Budget
RAINS	Regional Air Pollution Information and Simulation
RFF	Resources for the Future
SAGE	System for assessing Aviation's Global Emissions
SCSM	Stratus Consulting Spreadsheet Model
SMAAQ	Screening Model for Airport Air Quality
TAF	Terminal Area Forecast (FAA)
	or Tracking and Analysis Framework (DOE)
TRB	Transportation Research Board
VSL	Value of Statistical Life
WFD	Water Framework Directive
WTA	Willingness to Accept
WTP	Willingness to Pay

1 INTRODUCTION

Increasing the capacity of the aviation system is a priority for the U.S. Federal Aviation Administration (FAA). Demand for commercial aviation is expected to increase 3-fold over the next 20 years [JPDO, 2004] and today's aviation system will probably not be able to meet anticipated capacity needs over the next century [NRC, 2003; AERO, 2002]. One critical component to developing additional capacity is the mitigation of the environmental impacts of aviation. Environmental impacts are often the source of controversies that can lead to delays in infrastructure development and thus to constraints on capacity expansion.

The FAA has adopted a near-term strategy in its Flight Plan to work with local governments and airspace users to improve the capacity of the U.S. airspace system. The goal is to meet the projected demand in an environmentally sound manner [FAA, 2004]. Recognizing the importance of the issues for the longer-term, the Joint Planning and Development Office (JPDO) initiative on the Next Generation Air Transportation System (NGATS) has adopted a goal of *implementing environmental protection to allow sustained aviation growth* between now and 2025, including a vision for absolute reductions in significant impacts from aviation community noise and from certain local air quality pollutants [JPDO, 2004].

At the international level, the International Civil Aviation Organization (ICAO) also makes environmental protection one of its strategic objectives. Through its Committee on Aviation Environmental Protection (CAEP), ICAO undertakes various activities *to minimize the adverse effects of the global civil aviation on the environment* [ICAO, 2004] and "to achieve maximum compatibility between the safe and orderly development of civil aviation and the quality of the environment" [ICAO, 2001]. ICAO undertakes these activities with a goal of achieving harmonization across states and taking a "balanced approach" [ICAO, 2001]. These national and international policies and goals require a careful assessment and balancing of aviation's environmental impact with other societal objectives.

The FAA's Office of Environment and Energy (FAA-AEE), in accordance with the FAA's Flight Plan, the NGATS Integrated Plan, and the ICAO-CAEP mission, is developing a comprehensive suite of software tools that will allow for thorough assessment of the environmental effects of aviation. The main goal of the effort is to develop a new, critically-needed capability to assess the interdependencies between aviation-related noise and emissions effects and associated environmental costs. A central building block of these new software tools is the Aviation Environmental Design Tool (AEDT), which will integrate existing noise and emissions models with a new aircraft and engine analysis tool, referred to as the Environmental Design Space (EDS). To complete the suite of tools, AEDT and EDS will be components of a broader economic analysis capability, entitled the Aviation Environmental Portfolio Management Tool (APMT). The integrated capabilities of AEDT, EDS, and APMT will enable assessments of the global, regional, national, and airport-specific environmental impacts of aviation.

Specifically, for APMT, the goal is to provide policy-makers and stakeholders with the capability to evaluate the impacts of environmental policy alternatives in the form of social costs, such as public and private mitigation costs and public environmental benefits (*e.g.* improved societal welfare such as better health, reduced adverse socio-economic effects, *etc*.). This document contains the requirements for APMT, the development of which has been initiated in the third Transportation Research Board (TRB) Workshop on AEDT and APMT (January 31-February 2, 2005) [TRB, 2005]. First, an overview of environmental economics is presented in Section 2. Then, the methods available for valuing environmental goods are described in Section 3. Section 4 surveys the current practices for making environmental economic assessments. In Section 5, the past, current, and future practices in assessing environmental economics in the US and the international community are discussed. The stakeholders of APMT are then addressed in Section 6. Finally, the requirements of the APMT itself are given in Section 7, including the functional requirements as well as requirements for development and use.

Note that this Requirements Document is the first of a three-document series related to the development of APMT. The second document is an APMT Architecture Study that describes in detail the components of the APMT architecture, outlines the interfaces that will be required among those components, and establishes how APMT will interface with other tools that exist or are under development, including the EDS and the AEDT. The Architecture Study also reviews existing tools available for these types of analysis, assesses their suitability for use in APMT, and establishes the additional development that will be necessary to achieve APMT requirements. The third companion document is an APMT Prototype Work Plan that describes an initial APMT prototyping effort intended to identify gaps or weaknesses in the APMT architecture and to stimulate advancements in development. The Prototype Work Plan delineates all of the entities necessary for the analyses, their roles, data requirements, and proposed schedule.

2 OVERVIEW OF ENVIRONMENTAL ECONOMICS

2.1 Introduction

Economics is the social science concerned with resource usage. Definitions of economics emphasize the fact that resources are limited and human wants are unbounded, which implies that tradeoffs are necessary [Mankiw, 2004, p3]. Much of the study of economics focuses on production decisions of firms and on consumption decisions of individuals and households because both embody the problem of allocating limited resources across many potential uses. This is broadly known as microeconomics. In contrast, macroeconomics has a broader focus and is concerned with the flow of resources within and among economies. Economics applies to the study of the environment since many environmental problems, such as air and water pollution, result directly from the resource allocation decisions of individuals and firms. From an economic point of view, the environment is a resource with value which is implicitly or explicitly factored into production and consumption decisions. Further, addressing any of these environmental problems generally involves assessing the value that people place on the environment.

In environmental economics, the value of the environment used in analyses derives from the value people place on its resources [Kolstad, 2000, p32]. As a result, all impact to the environment is traced back to people—in terms of health, nuisance, or other effects. Any feature of the environment that people value is included in the field of environmental economics, even if quantifying these features poses methodological challenges. In contrast, there are other disciplines, such as ecological economics [Kolstad, 2000, p5], that try to quantify the value of the environment using biological and nature-based measures of value rather than anthropogenic measures of value.

Much microeconomic modeling proceeds from an optimization framework [Nicholson, 1998, p6], with the behavioral assumption that firms or individuals act in their own interest. In the case of individuals, this means that they make consumption decisions to maximize their well-being, and in the case of firms, production decisions are made to maximize profits. All decisions are based on resources that are available to the parties directly involved. In addition, decision-making is influenced by the information that those parties have about other parties and about future outcomes.

Because environmental resources are often common goods shared by many, and are often without explicit economic valuation, individuals and firms responding to economic incentives often make decisions without considering that such resource use can result in a suboptimal outcome for society as a whole [Russell, 2001, pp2-6]. Economic prescriptions for environmental policy efforts are designed to explicitly express the value of environmental resources to individuals and firms in order to result in outcomes closer to the social optimum.

For example, consider three parties living in a community: a manufacturer, a consumer, and a homeowner. The manufacturer produces goods the consumer buys, but at the expense of fouling the air and water of the adjacent homeowner.[4] If the homeowner values incrementally cleaner surroundings at a higher level than the value the consumer places on the last increment of the manufacturer's output, then this outcome is not optimal. Reducing emissions in this setting costs the manufacturer lost revenue and any explicit costs associated with changes to the manufacturing setup, and costs the consumer lost units of the manufacturer's output and higher prices on the available units of output. In return for these costs, the homeowner experiences an increase in well-being associated with the reduced emissions. With an environmental economic analysis, there is a compelling way to balance the competing interests of the homeowner, customer, and manufacturer and choose the level of pollution that maximizes well-being for society[5].

2.2 Environmental Economic Analysis

One of the ways in which economic analysis can guide policy decisions regarding the best option between the two extremes is through explicit accounting of the costs and

---

[4] The burden borne by the homeowner as a direct result of the emissions in this example is known in economics as an externality, specifically an external cost [Kolstad, 2000].

[5] In environmental economics, the levels of production and consumption that best maximize well being for society as a whole are referred to as the most "efficient" levels.

benefits associated with a regulatory change. This is known as benefit-cost analysis (BCA) or cost-benefit analysis [Kopp, Krupnick & Toman, 1997]. By choosing policy alternatives that result in the overall largest benefit net of cost, policy makers help maximize social well-being. A complete BCA requires that benefits of policy over a well-defined baseline be calculated in monetary terms, making costs and benefits directly comparable. Sometimes the output of BCA is presented as a ratio of benefits to costs instead of a net value. It should be noted, however, that, "attempts to use the benefit-cost ratio for any kind of ranking among options will lead to ambiguous results" [Callam & Thomas, 2000, p261]. The benefits net of costs (benefits minus costs) serves as a better nonbiased measure.

Although BCA is the recommended basis for assessing policy alternatives, there are other forms of economic analysis that are used. One of the most common of these is cost-effectiveness analysis (CEA). In most cases, the difference between CEA and BCA is in the treatment of benefits. Rather than comparing policies with differing costs and benefits, using benefits net of costs as the final measurement, policies are compared on the basis of cost when the policies being compared "have very similar types of desired outcomes" [Kopp, Krupnick & Toman, 1997, p 3]. This allows analysts to identify the policy representing the least cost for achieving a given benefit. In practice, some analysis is carried out under the heading of CEA that does not exclusively compare policies resulting in similar benefits. In these cases, this kind of analysis is carried out using benefits quantified in terms of a physical measure, such as tons of NO_x reduced, or numbers of people exposed to noise, to calculate benefit-per-dollar of cost of the policy. CEA produces reliable results when the policies being analyzed have identical or very close benefits. However, if there is a non-linear relationship between the intermediate physical measure of the benefits and the ultimate health and welfare benefit (as is often the case), then CEA can be misleading. Further, even when the intermediate physical measure is a good surrogate for the ultimate health and welfare effects, the most cost-effective policy could still be unwarranted (*i.e.* economically inefficient) if the policy costs exceed the benefits returned to society. When the amounts of benefits generated by policies vary, presenting the benefit per dollar spent on different policies can have the same problems associated with ratios described above. "Cost-effectiveness analysis does not necessarily reveal what level of control is reasonable, nor can it be used to directly compare situations with different benefit streams" [EPA, 2000, p178].

While BCA can be used to evaluate whether a program results in an overall improvement for society, sometimes policy analysis requires assessing which segments of the economy or parts of society receive the benefits and which segments bear the costs. This is broadly termed distributional analysis (DA). Sometimes DA is required by specific legislation, such as by laws designed to offer special protection to segments of society deemed to be vulnerable, for example, children, the elderly, or minorities. This also could be used to assess the feasibility of a particular policy solution, knowing that policies are more likely to be successful when costs are equitably distributed as opposed to heavily concentrated on one segment of society, be it individuals or businesses. Economic Impact Analysis (EIA) and equity assessment are two ways in which this distributional analysis can be carried out [EPA, 2000, p20]. Both generally focus more on the negative impacts of a policy and highlight what would likely be experienced by particular segments of society. EIA is often primarily concerned with identifying "winner and losers." Equity analysis focuses particularly on the vulnerable segments of society and may be informed by BCA and EIA to the extent to which output can be disaggregated and population segments be identified.

All of these common forms of environmental economic policy analysis require quantitative (*preferably monetary* [EPA, 2000, p59; FAA-APO, 1998, p2-3; OMB, 2003, p11; OECD, 1995, p23; UK HM Treasury, 2003, p22]) measures of the costs and benefits measured relative to the baseline case or status quo (no policy change) case. Consequently, a number of academic, government, and industry research efforts have focused over the past thirty to forty years on developing and refining the techniques of quantifying costs and benefits of environmental policies. Likewise, a significant fraction of environmental economic research has been performed to improve understanding of the situations from which environmental problems arise and to define optimal policy mechanisms [see, for example, Kolstad, 2000 and Freeman, 2003].

2.3 Policy Benefits

The primary benefit of a policy intervention in an environmental problem is harm avoided or reduced. There are many forms this harm can take including physical health, nuisance, aesthetic, and legacy value to future generations. Producing economic values for some of these types of harm requires a layered, interdisciplinary approach. The first layer is the physical environmental modeling to determine how the policy under examination will impact the physical presence of the particular pollutant(s). From there, additional layers of analysis, such as medical analysis of health impacts, could be required. Wherever possible, the final economic layer places a monetary value on the harm avoided. Using a monetized value of the benefits of policies allows for direct comparison of benefits with policy costs and allows for summation of different types of benefits in a common unit of measurement.

Economists' primary ways of talking about this value of harm is Willingness to Pay (WTP) for improvements in environmental quality or Willingness to Accept (WTA) compensation for degraded environmental quality [EPA, 2000, p60]. Relating this to the example in Section 2.1, from a starting point of zero pollution with the homeowner controlling the scenario, the homeowner might be willing to accept some pollution if the manufacturer pays him or her for the opportunity to operate. Likewise, starting from an initial position with the manufacturer polluting as much as he or she wants, the homeowner would be willing to pay the manufacturer to curtail some output and pollute less. The magnitude of the WTP or WTA is proportional to how the homeowner feels about the pollution, the cost of any physical damages to his or her property or health, and so on.[6]

---

[6] These two measures can differ. For a brief discussion of why, see EPA, 2000, p60.

In addition to harm avoided, environmental policy can create indirect benefits to society that should, where possible, be taken into consideration. These indirect benefits may include factors such as job growth in industries that generate products that mitigate environmental harm.

Techniques for monetizing benefits (estimating WTP or WTA) will be discussed in Section 3.

2.4 Policy Costs and Policy Mechanisms

The primary costs of environmental policy are the direct costs of reducing environmental impact. These costs are sensitive to the type of policy measure being considered. This means that a basic understanding of the range of policy options is necessary to understand the different modeling considerations for costs. For instance, if a policy requires that a specific kind of equipment be installed by a polluting industry, then the cost of installing that equipment is the primary cost of the policy. However, for other types of policies, for instance, market-based options, the costs will not necessarily be so easily estimated and may require different frameworks.

Standards that require a particular technology be employed by polluters to mitigate pollution can be an economically inefficient form of regulation, though they may be the easiest for which to estimate direct compliance costs [Kolstad, 2000, p140]. Some standards mandate a particular technology that must be applied by each firm to achieve the regulator's goals, independent of the individual polluter's characteristics. However, because production means, procedures, and technologies vary across firms, so do the costs of mitigation. Therefore, the least costly means of achieving a particular industry-wide level of emissions may be to have some production units emit less than others, within firms and across the industry [Kolstad, 2000, p141]. Most forms of standards do not allow for this cost-saving variation.

Other forms that standards may take include specifying emission limits, which may also be known as caps or stringencies. When these are applied uniformly across polluters, independent of the individual characteristics, they are often not the most efficient method of regulation. However, because they allow firms to choose the technology with which they meet the standard, they represent some potential improvement over required abatement technologies. Estimating direct compliance costs would require understanding how different firms adopt different techniques to meet the cap.

Non-uniform standards require a particular technology or level of abatement that varies, depending on the individually-regulated polluter's existing technology (for example, old factories vs. new factories, or pistons vs. jets) in contrast to a uniform standard. For example, older coal-fired power plants may face much higher abatement costs than more modern plants. This may lead a regulator to set a standard for each technology level in the industry. While politically unpopular, this approach can lead to lower cost of abatement than uniform stringencies or uniform technology standards, but with a higher requirement for information [Kolstad, 2000, p141].

The preceding regulatory styles all fall under the heading of what is generally labeled by economists as command and control regulation [Callan and Thomas, 2000, p99]. The alternative to the command and control approach is known as incentive-based or market-based regulation. Market-based regulatory options include fees charged to polluters for emissions that they generate, as well as emission credits or permits for the right to generate a particular amount of emissions that can be traded amongst polluters.

Market-based regulatory options are desirable because they prompt innovation on the part of regulated polluters [Harrington et al, 1999] and because they prompt firms to include environmental costs in their decision-making, while accommodating different characteristics amongst firms. For example, if a polluter is charged a fee for its emissions, there are many choices it could make to maximize profit in light of the fee. It could reduce production of the output that is responsible for the emissions, change its operating procedures for using its existing technologies, adjust the mix of inputs it uses, or invest in new lower emission technologies. The variety of means by which firms respond to incentives makes it challenging to calculate costs for purposes of BCA and CEA. This is because such calculations require anticipating innovation. It has been found that per-unit regulatory cost estimates for pollution abatement are often too high owing to technological innovation that is difficult to anticipate [Harrington et al, 1999].

Moving beyond direct mitigation costs, the cost of a policy can be considered to be the value of everything (opportunity costs) that is given up if that policy is adopted. This concept, known as social cost, can be defined as "the sum of the opportunity costs incurred by society because of a new regulatory policy; the opportunity costs are the value of the goods and services lost by society resulting from the use of resources to comply with and implement the regulation, and from reductions in output" [EPA, 2000, p113]. In addition to the direct mitigation costs, social cost would include such factors as any jobs lost in the regulated industry, any costs for government oversight and ongoing administration of the policy, and any wider impact on the economy. Table 1 details some of the costs across the categories. Tracking who pays all of the costs that accrue allows for analysis of the distributional consequences of the policy.

The kinds of models used to address social costs depend on the specific types of costs being estimated. Direct compliance costs could, for instance, be estimated using an engineering approach. Government sector costs could be estimated by looking back on the government resources that have been required for efforts of a comparable scale and complexity. Partial equilibrium analysis focused on the directly affected markets can capture some of the welfare and transitional costs, while general equilibrium analysis incorporating the interplay of different markets across the whole economy is required to capture all of the welfare and transitional costs [see for example, Nordhaus 1996].

Table 1. Common cost categories used in environmental economic analysis [EPA, 2000, p120]

Social Cost Category	Examples
Real-resource Compliance Costs	• Capital costs of new equipment • Operation and maintenance of new equipment • Waste capture and disposal, selling, or reuse • Change in production processes or inputs • Maintenance changes in other equipment
Government Sector Regulatory Costs	• Training/administration • Monitoring/reporting • Enforcement/litigation • Permitting
Social Welfare Losses	• Higher consumer and producer prices • Legal/administrative costs
Transitional Social Costs	• Unemployment • Firm closings • Resource shifts to other markets • Transaction costs • Disrupted production
Source: Adapted from Harrington et al. (1999).	

2.5 Application

Inclusion of some types of costs and benefits in an analysis will depend on the audience. For instance, in the United Sates, the Office of Management and Budget (OMB) does not allow inclusion of economy-wide "multiplier effects" in either costs or benefits for regulatory policy analysis [OMB, 1992, p6] and likewise specifies that the focus of analysis for U.S. programs should be on U.S. benefits rather than international benefits [OMB, 9992, p5].

The specific form of any economic analysis depends on its audience. APMT users and stakeholders will be discussed in Section 6.

3 MONETIZATION OF BENEFITS

3.1 Introduction

The previous section provided an overview of the field of environmental economics and began to describe the role of monetized policy benefits in different forms of economic analysis. This section provides additional detail on valuing reductions in pollution for purposes of economic policy analysis. The United States Environmental Protection Agency (EPA) advises that,

> “[t]o the extent feasible and warranted by their contribution to the results, as many of the effects of a policy as possible should be monetized. This enhances the value of the conclusions to policy makers weighing the many, often disparate consequences of different policy options and alternatives.” [EPA, 2000, p176]

Likewise, the Federal Aviation Administration’s Office of Aviation Policy and Plans (FAA-APO) requires that “the value in dollars of all quantifiable benefits and costs be estimated” when carrying out benefit-cost analysis [FAA-APO, 1998, p2-5] and notes that,

> “[b]ecause the ultimate objective of benefit-cost analysis is the comparison of benefits and costs, they both must be evaluated in the same unit of measurement. It is rare that anything other than dollars (or another monetary unit) proves to be satisfactory.” [FAA-APO, 1998, p2-3]

This idea is echoed in policy guidance outside the United Sates as well:

> “The purpose of valuing benefits is to consider whether an option’s benefits are worth its costs, and to allow alternative options to be systematically compared in terms of their net benefits or net costs. The general rule is that benefits should be valued unless it is clearly not practicable to do so” [UK HM Treasury, 2003, p22].

> “For many types of environmental “goods” … there are simply no markets, and economists have to resort to other valuation methods. For other environmental assets, the market price fails for various reasons to signal their true scarcity. However, where markets operate reasonably well, prices will give a reliable indication of good’s relative scarcity” [OECD, 1995, p23]

Placing monetary values on the estimated reduction in pollution resulting from proposed environmental policies allows:

- aggregation of the benefits of pollution reduction across different impact pathways (e.g. a pollutant that produces impacts on air quality and water quality)
- direct comparison of the benefits associated with reducing different kinds of pollution (e.g. noise and airborne emissions)
- calculation of policy benefits net of policy costs for determining the improvement in society’s net well-being associated with a policy option (benefit cost analysis)

From an economic perspective, it is necessary to be able to perform these comparisons and calculations to choose the policy intervention that most improves social well-being. In the absence of monetized benefits of pollution reduction, policy analysts cannot rank potential policies according to what society values, which could result in under- or overproduction of pollution relative to what maximizes social well-being. In the case of policy benefits that are difficult to monetize, it is generally advised, by the EPA and others such as the OMB, that these benefits be as clear and quantitative as possible.

Most commodities are valued in the marketplace where their prices are determined by the interactions of buyers (demand) and sellers (supply). When a policy analyst needs to place a value on a good for which a market exists, such as a piece of equipment or hours of labor, the analyst can use the market price of the good. The price reflects the payment required on the market to garner a commodity for one use to the exclusion of all other uses. The party that pays the price to buy the commodity must place a value on that commodity at least as great as the price; otherwise, he or she would not have bought it.

In some cases, a market does exist that directly allows valuation of an environmental good (known as market methods) [EPA, 2000, p71], such as benefits for commercial fisheries (the market price of fish) and commercial timber (the price of timber). However, in most cases no market exists for environmental quality, which is why environmental attributes are often referred to as non-market goods. This means that we cannot observe a price in a market for the environment to determine the value that society places on it. This does not mean that society does not value environmental quality—members of society place value on the environment and as such have a willingness to pay (WTP) for improvements in environmental quality. WTP, which is discussed in the previous section along with willingness to accept (WTA), is comparable to the price someone would be willing and able to spend on improvements in environmental quality, as if a market for environmental quality actually existed. It is important to take WTP into account in environmental cost benefit analysis because it reflects how people value a specific improvement in the environment relative to all other possible uses of funds, including other possible environmental improvements or non-policy uses.

There is no reason to expect that every individual values the environment in the same way. When monetary values are developed and applied to environmental analysis by EPA or by European Commission DG Environment, the purpose is to determine the value that society, collectively or on average, places on environmental amenities, even though individuals may have preferences higher or lower than other members of society. This extends to consideration internationally as well:

> "Monetary valuation of control actions and of health and environmental effects may be different in concept and vary substantially from country to country. In addition to variations in assessing costs, the relative value of benefit categories, such as benefits to health or building materials, will vary. Thus, the result of comparing costs and benefits in two areas with otherwise similar conditions may differ significantly" [WHO, 2000a, p50].

3.2 Types of Benefits

The techniques available and ability to estimate WTP values depend on the type of environmental quality being valued. Environmental amenities could have either use or non-use values, or both. Having use value for an aspect of the environment requires direct interaction or planned interaction with the environment [Kolstad, 2000, p295]. For example, we all breathe air, and thus have use value for the ambient air quality. Aesthetic values directly experienced have use values. Human health impacts, including mortality (death) and morbidity (disease), fall under the use heading as does exposure to noise, visibility, recreational quality, *etc*.

However, individuals may also have non-use value for quality in the environment even where the particular environment is not personally experienced [Kolstad, 2000, p 296]. Non-use value could derive from paternalistic altruism, knowing that if air quality improves someplace, people will have better health. Another form of non-use value is existence value. For example, an individual living in Kansas who never plans to travel to the ocean may have willingness to pay to protect whales just because he values the existence of whales. Legacy, or bequest, values are yet another form of non-use value. If an aspect of the environment has legacy value for someone, it is because he or she wants it to be experienced by future generations. The scenic beauty of the Grand Canyon may induce existence and legacy value for people who never intend to visit it, as well as direct use value for the millions of tourists who visit it each year.

A single policy intervention could produce multiple sources of benefit. For example, a policy that would reduce an amount of an airborne pollutant might have impact on mortality, morbidity, and visibility. When developing an estimate of the benefits associated with such a policy, each of these sources of benefit from the policy should be taken under consideration. EPA guidance recommends using this “effect by effect” approach, first beginning by identifying all sources of benefit, then quantifying those benefits, and finally estimating monetized values of the benefits, considering different methods of valuation where appropriate and being careful to avoid double counting [EPA, 2000, p6]. This could mean separating mortality versus morbidity risk associated with individual types of emissions.

The specific quantified form of the benefit being valued varies by benefit and may imply more than one rational option. Mortality risk reductions associated with policy intervention are typically quantified in number of statistical lives saved. Therefore, monetizing mortality benefits requires putting a value on statistical lives known as the value of a statistical life (VSL) [EPA, 2000, p87]. This quantification often makes people uncomfortable because it evokes putting a price on human life. It should be noted, however, that the value of a statistical life does not refer to any particular individuals and does not refer to the occurrence of a particular instance of mortality. People who are uncomfortable with the concept of valuing statistical lives should consider that an undesirably low number of statistical lives may be saved by policy if society’s value for them is not estimated. Other quantifications may include statistical incidence for morbidity, days per year of a particular clarity for visibility, and number of people exposed to a particular noise level, among many others. Care needs to be taken in choosing and valuing the metric when more than one is available—for instance, life years may be substituted for statistical life.

Techniques for estimating monetized values of environmental quality for valuing policy options fall into two broad categories: a) revealed preference methods, which use an indirect approach relying on measured data from market transactions to infer value for non-market environmental quality, and b) constructed market and stated preference approaches, which use a direct approach. The following sections provide descriptions of these different types of analysis. Note that these descriptions represent an overview of the techniques and issues for each analysis, and make no attempt at providing a level of technical detail sufficient for carrying out these types of analysis.

3.3 Revealed Preference Methods

Revealed preference methods for valuing benefits from policy use real market data, but manipulate these data further to attempt to *reveal* estimates of WTP. In this category, one of the most basic approaches to putting monetary values on the benefits of policy options involves summing the direct monetary damages associated with the harm avoided by the policy. When this approach is taken to place a value on avoided morbidity, the technique is known as *Cost of Illness* (COI). COI involves totaling the direct medical costs and lost income from missed working days associated with pollution-caused illness. A per incidence COI value can be applied to estimated avoided incidences. A similarly basic approach is known as *Averting Behavior*.[7] Using averting behavior to value environmental quality improvements requires summing costs that affected parties incur in trying to avert or mitigate harm from pollution. For example, for noise pollution this approach would include the cost to affected home owners of installing noise dampening insulation. This approach can be extended to mortality risks "by observing purchases of items that reduce the risks of dying in an accident. These applications are sometimes known as consumer market studies." [EPA, 2000, p80] COI and averting behavior methods have been applied to the valuation of noise reduction, but likely underestimate[8] the true costs since the expenditure surrogates they employ do not represent a removal of the source of harm (noise or illness). This means they are not capturing WTP.

3.3.1 Hedonic price analysis

Hedonic pricing analysis is one of the most common of the revealed preference methods. It assumes that the price of a commodity or good determined in a market comes from separable attributes of the good [Freeman, 203, p399]. This means that in statistical analysis (regression), the price of a good is broken up into what the effective prices are for the different characteristics of the good, one of which is related to the benefit that is going to be valued. This requires a clear quantifiable definition of the risk or existing pollution problem that a policy will address, and many observations of the good whose price is affected by the pollution problem at various levels of pollution.

Hedonic analysis is probably best understood by looking at specific applications. One of the most common is hedonic wage risk analysis. Wage risk analysis assumes that jobs have different characteristics, such as skill and education requirements [Freeman, 203, p399]. The characteristic focused on for evaluating environmental policy benefits is mortality risk—some jobs are more dangerous than others. When holding constant the skills and other characteristics of the job using statistical regression analysis, the value

---

[7] Also known as *defensive expenditure*.

[8] Emerging theories suggest that what was previously considered a strict underestimation associated with these valuation methods may not be the case. See Shogren and Crocker (1999).

the labor market places on risk can be identified. Applying this method requires being able to quantify risk as well as qualify the other important characteristics across different jobs with many observations.

Another useful application of hedonic analysis uses housing prices to estimate how people value exposure to spatially distinguishable environmental problems, such as noise exposure. This approach requires having data from the housing market that details the size and features of individual houses, as well as data that characterize their individual levels of exposure to the pollution problem addressed by the policy under examination. The house price can then be statistically decomposed using regression analysis into the values the market places on its features, such as size, number of bedrooms, and exposure to the pollution problem.

Hedonic methods have the advantage of drawing on actual market data—something encouraged by OMB [OMB, 1992, p6]. It is important to also recognize that there are some limitations to hedonic analysis. For instance, relatively few markets produce prices that are well correlated with a mortality risk or environmental quality. Likewise, the estimation process requires data that can be difficult to acquire. Additional limitations include the assumption that the market in question is in equilibrium.

3.3.2 Travel cost recreational demand

As another example of revealed preference methods, the *travel cost recreational demand*[9] has been most widely applied to water quality studies where the choice of fishing or swimming site depends on water quality at the site. Other applications of recreational demand include valuing species diversity for bird watching, marine diving, visibility in scenic settings, and desire for serenity or natural quiet.

> "Consumption of an outdoor recreation site's services requires the user to incur the costs of a trip to that site. Travel costs serve as implicit prices. These costs reflect both people's distances from recreation sites visited and their specific opportunity costs of time." [Phaneuf and Smith, 2004]

When these data are then collected concerning the costs of traveling to different sites, including the relative distances, the relative costliness can be used to value the environmental amenities at one site. In this way, the relative cost of one site over another is used as a price. These approaches, particularly when they deal with multiple sites and multiple environmental attributes, often use statistical tools such as probit and nested logit techniques that are more sophisticated than standard regression analysis.

3.4 Constructed Markets and Stated Preference Methods

Rather than inferring value from considering other goods, constructed market and stated preference approaches, try to directly assess values through survey or experimental settings. These direct approaches are capable of being used to assess non-use values,

---

[9] Also referred to as just *travel cost models* or *recreational demand model*s, some utilizing particular techniques are also referred to as *Random Utility Models* (RUM).

which revealed preference studies cannot. As a result, they have been widely employed by organizations such as the EPA Office of Water in areas where non-use values are thought to be high, and where appropriate data for revealed preference studies are limited or nonexistent (for example see [EPA, 2002]). *Contingent Valuation* (CV) is the dominant method in this arena. CV methods are based on the use of surveys to directly elicit willingness-to-pay (or willingness-to-accept) from relevant parties. In the survey, an individual is presented a hypothetical situation and a questionnaire follows, giving the individual a choice of actions. The responses are used to develop WTP estimates.

Four steps are entailed in developing a CV study. First, a market scenario is defined. This is followed by the important question of how to ask respondents about their willingness to pay (the elicitation method). A study design is developed, including decisions on how to administer the survey, choose the appropriate subject population, and establish an experimental design. Finally, with the results, demand functions can be derived through statistical means. As with the hedonic pricing method, the objective is to estimate a marginal damage curve as a function of environmental quality.

Once the survey is defined, the important choice must be made as to how to acquire valuation responses. The payment mechanism suggested may be the proposal of a fee or an out of pocket expenditure, or may simply be a direct question about WTP. The last of these represents one method of elicitation, a direct expression of value. Other methods include referendums, where a respondent is asked to answer yes or no to a discrete payment amount. These are valued for their similarity to voting circumstances. Bidding games are initialized by the suggestion of a WTP value, followed by either the continual increase or decrease of values until no changes to yes, or vice versa.

Once an elicitation method is chosen, the survey can be administered to a sample population, which has perhaps gone through a prescreening process to identify characteristics that would make them good candidates for the study. A random sample is then drawn and the survey conducted among selected respondents. An appropriately planned experimental design can reduce the need to sample large numbers of people.

As stated above, the strength of the CV method lies in its ability to estimate the total value of a change in environmental quality. With proper design, CV studies for noise and air quality can be cost-effective to undertake. However, difficulties in sampling and eliciting unbiased responses may exist in the application of this method to areas with low population density.

When CV started becoming more prevalent during the late 1980s and early 1990s, in particular when researchers started exploring the use of this method to calculate non-use values for damages associated with events such as oil spills [Portney, 1994], there was considerable debate amongst economists as to the validity of any estimation approach that does not use real market data [Diamond and Hausman, 1994]. Among the chief complaints against CV is the fact that people surveyed do not actually pay with their own money; instead they are asked to make hypothetical choices. In practice, there are some bodies, such as EPA, that accept the careful use of CV estimates, while others do not accept them. Overall, the debate has raised the level of care and attention to detail exercised in carrying out and using the results from CV studies.

3.5 Valuation of Benefits to Children and the Elderly

Executive Order 13045, "Protection of Children from Environmental Health Risks and Safety Risks," states,

> "A growing body of scientific knowledge demonstrates that children may suffer disproportionately from environmental health risks and safety risks. . . . Therefore, to the extent permitted by law and appropriate, and consistent with the agency's mission, each Federal agency: (a) shall make it a high priority to identify and assess environmental health risks and safety risks that may disproportionately affect children; and (b) shall ensure that its policies, programs, activities, and standards address disproportionate risks to children that result from environmental health risks or safety risks." [Executive Order 13045]

It may be the case not only that different levels of quantified benefit (such as incidence of morbidity) accrue to children for a particular exposure to pollution, but also that different dollar values may apply to it. However, values for children are not always established and often are difficult to estimate. EPA guidance on valuing children's health provides extensive advice on using adult values from the types of methods described above. EPA also provides advice on how to qualitatively characterize the differences in incidence to children when quantitative methods are not available. Additionally, children should be considered as a category in any distributional analysis such economic impact analysis or equity analysis.

The elderly are another group who are often differentiated in distributional analysis. There is some logical argument, though it may be disturbing, that because the elderly have fewer years of life left, the values applied to their mortality and morbidity risks should be less. Some hedonic wage studies [Aldy & Viscusi, 2004] support this argument empirically, but in general the practice is not carried out. In practice, the elderly are highlighted in equity analysis for the same reasons low income families are—to ensure that effects on vulnerable populations are cataloged.

3.6 Benefits Transfer

Benefits transfer refers to the practice of applying benefits calculated in one study to economic analysis in another study, for instance, if an analyst draws a value of statistical life estimate from a previous study and applies it to the policy analysis at hand. Even though analysis in previous valuation studies may not be specifically tailored to the setting being examined,

> "The advantages to benefit transfer are clear. Original studies are time consuming and expensive; benefit transfer can reduce both the time and financial resources needed to develop benefits estimates of a proposed policy. Given the demands of the regulatory process, these considerations may be extremely important. Additionally, while the quality of primary research is unknown in advance, the analyst performing a benefit transfer

is able to gauge the quality of existing studies prior to conducting the transfer exercise." [EPA, 2000, p86]

EPA provides the following guidelines on applying benefits transfer [EPA, 2000, p96]:

- carefully describe the policy case;
- assess the quality of the studies and their applicability to the policy case;
- evaluate the plausibility of the findings;
- consider possible adjustments for differences between
- the subject of the study and the policy case; and
- explicitly address uncertainty.

Additionally, previous studies can be applied as a range or distribution of values, enriching the analysis beyond a single estimate and acknowledging the uncertainty of the estimates.

3.7 Application of Monetized Benefits Techniques

Table 2 presents value of statistic life (VSL) estimates from EPA Guidelines, as well as values that have been used by other U.S. government agencies, and the value presented in the Benefit Table Database developed by National Environmental Technology Center for the European Commission (see section 4.1.2). These values have been used in specific analyses sponsored or undertaken by these agencies.

Table 2 Value of statistic life (VSL) estimates

Source/User	Value of Statistical Life in 2000 dollars
EPA [EPA, 2000]	$6,067,380
Department of Energy's TAF [ANL, 1996]	$3,938,280
Food and Drug Administration [Kenkel, 2000; FDA, 1999]	$1,224,240
European Commission's BeTa [NetCen, 2002]	$924,920
USDA [Kenkel, 2000]	$735,990

EPA bases its VSL recommendation on carefully reviewed studies from the academic literature, some of which use hedonic techniques in the labor market while others use CV. In general, the values from the CV studies are no higher or lower than the hedonic studies. The EPA value in Table 2 reflects EPA's recommendation of $5.8 million dollars in 1997 dollars that is the central value of the studies they reviewed. To reflect uncertainty about the “correct” VSL, all of the values from the studies could be taken into account probabilistically. Additionally, bounding analysis using high and low estimates could be performed as well as calculating the level of value of statistical life required to reverse the conclusions of the benefit-cost analysis (i.e. the amount VSL would have to decrease for the policy not to beneficial to society). Analysis that explicitly takes the distribution of estimates of value of statistical life under consideration would be the most thorough way of incorporating uncertainty about these values into the analysis.

Uncertainty is present in almost any form of modeling—this is why we refer to the output of such models as estimates. This uncertainty should not be considered to be a limiting factor to the application of these techniques for valuing non-market environmental goods. This uncertainty should be acknowledged, but so long as estimates are carried out in a methodologically sound manner, with transparency in assumptions, and applied carefully, using these kinds of estimates enriches policy analysis and answers important questions that cannot be answered otherwise, such as what one kind of pollutant is worth to society relative to another one.

4 CURRENT PRACTICES IN ENVIRONMENTAL ECONOMIC ASSESSMENTS

The purpose of this section is to provide a general review of environmental economic assessments performed in fields other than aviation. In Section 5 we will review the current practice within aviation. This comparison suggests that there are opportunities for significant improvement in the tools and techniques applied in analyzing environmental policy for aviation.

4.1 Analyses Performed by Agencies Other Than FAA and ICAO

4.1.1 U.S.

In the United States, the majority of environmental economic analysis and assessment within the government is carried out by EPA. Much of this analysis is carried out in support of setting requirements under specific pieces of legislation, such as the Clean Air Act. Table 3 is drawn from the report *Regulatory Economic Analysis at the EPA* [Anderson & Kobrin, 2000] that details the kinds of analysis required by specific parts of United States Federal Legislation.

Table 3. Analyses Specified in EPA's Enabling Legislation

	Benefits			Costs		
Act/Regulation	Pollution Reduction	Health	Welfare/ Environment	Compliance Costs	Cost- Effect	Economic Impacts
Clean Air Act						
NAAQS - Primary	X					
NAAQS - Secondary			X			
Hazardous Air Pollutants	X	X				
New-Source Standards	X	*	*	**	**	**
Motor Vehicle Standards***	X	X	X	X	X	X
Aircraft Emissions	X	X	X	X		X
Fuel Standards***	X	X	X	X		
Clean Water Act						
Point Sources	X		****	X	X	X
Publicly Owned Treatment Works	X					
Safe Drinking Water Act						
Max. Contaminant Level Goals		X				
Maximum Contaminant Levels	X	X		X		X
Toxic Substances Control Act	X	X	X	X	X	X
Resource Conservation and		X	X			
Comprehensive Environmental						
Reportable Quantities		X	X			
National Contingency Plan	X				X	
Federal Insecticide, Fungicide, and						
Data Requirements			X			
Minor Uses	X	X	X	X	X	X
Atomic Energy Act						
Radioactive Wastes	X	X	X			
Uranium Mill Tailings	X	X	X	X	X	X

** Includes non-air-quality health and environmental impacts only.*
*** Statute refers only to "cost."*
**** Type of analysis depends on grounds for control.*
***** Includes non-water-quality environmental impacts only.*

Additionally, in its 2003-2008 Strategic Plan [http://www.epa.gov/ocfo/plan/2003sp.pdf], EPA carries out agency level benefit-cost analysis of its overall activities in different areas.

EPA is subject to the same requirements for economic analysis that all Federal agencies in the United States face, specifically including those put forth in Executive Orders (*e.g.* Executive Order 12866) and Office of Management and Budget (OMB) Circulars (e.g. Circular A-4). In part, EPA's practices for economic analysis are as developed as they are due to the Executive Orders of the past twenty years and more, requiring that accounting of social benefits and costs be carried out for all regulatory programs, including environmental. OMB specifically offers guidance on the range of discount rates to use in discounting future streams of value to the present, prohibits accounting for multiplier effects in costs or benefits, and advises that wherever possible, benefits from a particular regulatory policy be expressed in monetary terms allowing for their direct comparison to costs.

EPA has developed its own set of guidelines [EPA, 2000] for carrying out economic analysis that complement OMB guidance and go into significantly more detail specific to economic analysis. These guidelines are heavily referenced in this document and the range of analysis described is consistent with those presented here.

EPA maintains extensive relationships with academia and offers grants (see e.g. http://yosemite1.epa.gov/ee/epa/eed.nsf/Webpages/Grants.html) for specific research that is considered at the frontier of current techniques. The Office of Water has historically been a strong supporter of these cutting edge studies because many non-use values can only be captured through sophisticated survey design.

4.1.2 International

In the European Union (EU), environmental policy guidance and legislation are developing. Directives issued by Europa EU-Lex, the EU governing body, to establish broad, high-level expectations regarding environmental cost and benefit analysis, but do not detail methods (*Official Journal of the European Union* [http://europa.eu.int/eur-lex/en/index.html]). For instance, the Water Framework Directive (WFD) requires EU member states to conduct an economic analysis of water use for every river basin by the year 2004. According to the German Ecologic entity [http://www.ecologic.de] "So far experiences with such analyses are rare in Germany as well as in other EU member states, and no detailed guidelines about the basic approach and methods to be used for the realisation of the economic analyses are given in the Directive."

The goal of the European Environment Agency (EEA), established in May of 1990, is, "To provide the Community and Member States with objective, reliable and comparable environmental information" as defined in Regulation 1210/90. Their focus is to provide the best available environmental information to policy makers, the public authorities, and socio-economic agents, and to the public to maximize environmental stewardship. The EEA has assembled a large library of documents, reports and databases listed by topic on their website: http://reports.eea.eu.int/index_table?sort=Thematically. The EEA focus is on collecting and disseminating this information to the broad community concerned with environmental use and policy development. In conjunction with the Organisation for Economic Co-operation and Development (OECD), the EEA is collecting information on instruments used for environmental policy and natural resources management, as shown on the following website: http://www2.oecd.org/ecoinst/queries/index.htm.

Under the auspices of the Europa EU-Lex governing body, there are ongoing environmental economic analyses. One example is an effort to improve and expand the usage of benefit-cost analysis in Europe and the rest of the world by developing a database referred to as the Environment Valuation Reference Inventory (EVRI) [EEC, 2002]. This database is a collection of economic values that may be used for benefits transfer applications (see Section 3) to estimate changes in environmental goods and services or human health. The database includes, for example, estimates of the impact of noise on property values, using hedonic property pricing and revealed preference techniques, and a range of values for environmental impacts of urban traffic using stated choice techniques.

Other database efforts include the BeTa (Benefits Table Database) [http://europa.eu.int/comm/environment/enveco/air/betaec02a.pdf], developed by National Environmental Technology Center for the European Commission. It models impact pathways to trace emissions dispersion and assigns willingness-to-pay values to exposure and environmental impacts. The EEA and OECD administer a database of economic instruments used for environmental policy and natural resources management. The database is populated by information from OECD and EEA member states, as well as additional cooperative states, and includes data on the use of environmental taxes, fees and charges, tradable permit systems, deposit refund systems, subsidies, and voluntary approaches. For example, a query on revenues raised by environmentally-related taxes for a selected country returns the type of tax, the year instituted, and the total revenues raised by the tax.

A number of models exist that are used to carry out policy analysis in countries other than the United States. These include:

- The Asia-Pacific Integrated Model (AIM), developed in the mid-1990s with funding from the Ministry of Environment of Japan, is a set of integrated computer simulation models for evaluating policy options to mitigate climate change, air pollution control, water resources management, land use management, and environmental industry incentives.
- Regional Air Pollution Information and Simulation (RAINS), developed in 1998 for a European Commission, analyzes the features of cost-effective approaches to control European air quality, including emission reduction strategies, especially acidification, eutrophication, and tropospheric ozone. In addition, there are separate modules for emission generation, control options, costs, atmospheric dispersion, and environmental sensitivities for 38 regions in Europe over 22 categories of fuel use in 6 economic sectors.
- Canada developed a model for a 2002 study that presents results in terms of changes in output in energy-supplier and energy-intensive sectors and economy-wide changes in GDP.
- Modeling efforts have been applied to EU economic evaluation of the European Community's 2030 Kyoto Protocol targets. They were geared toward identifying least cost policies as well as measures for meeting EU greenhouse gas emissions reductions. Costs associated with CO_2 reductions, as well as the effect and ramifications of trading scenarios, were analyzed.

4.2 Focus of Current Environmental Economic Research

The environmental economic analysis and research taking place outside government agencies is more extensive than that being carried out by government agencies. This literature is primarily published in academic journals, books, and on the internet. One concentrated repository for environmental economic analysis is Resources For the Future (RFF), an environmental economics organization founded in 1952. Most of the scholarly research carried out in the field takes place at universities. Other organizations, including PEW, the Brookings Institute, and the American Enterprise Institute, carry out environmental economic analysis, as do nongovernmental organizations such as the Center for Climate Change.

The points discussed in Sections 4 and 5 of this document originally stem from academic literature and it is along these themes—policy analysis, cost estimation, benefit estimation, and market-based policies—that much of the literature continues. The literature is wide-ranging and diverse. A search on a well known database of economics journals using the key phrase “environmental economics” reveals more than 600 papers published in 2004. A search on “pollution” yields more than 400. This means that summing up the current state of the literature is no small task.

The following themes are prevalent in the recent academic literature:

- Continuing refinement of monetized benefits and reconciling/validating differences among countries and regions around the globe
- Continuing focus on air quality and water quality—growing focus on climate change
- Studies of sustainable development, especially in developing countries
- Focus on financing of “green” development in developing countries
- Market solutions such as permit trading in theory and in practice
- Ongoing work on non-market based policy options
- Continual revision and expansion of old themes

5 PAST, CURRENT, AND FUTURE PRACTICES IN AVIATION ENVIRONMENTAL ECONOMIC ASSESSMENTS

This section provides an overview of past aviation environmental analyses that have been performed, as well as the current practices. This is shown in particular for the U.S. and the FAA, as well as for entities outside the FAA, both nationally and internationally. Furthermore, future needs as described by the various entities are also stated. The purpose of this review is to provide a foundation for the detailed APMT requirements described in Section 7. In this context, both the capabilities of the existing tools as well as the questions that the tools are used to address are described.

5.1 U.S.

5.1.1 FAA environmental economic analysis

The FAA is directly responsible for the development of several analysis tools, namely the Emissions and Dispersion Modeling System (EDMS), Model for Assessing Global Exposure to Noise from Transport Aircraft (MAGENTA), Integrated Noise Model (INM), System for Assessing Aviation's Global Emissions (SAGE), and Screening Model for Airport Air Quality (SMAAQ). These tools are also shared with ICAO's Committee on Aviation Environmental Protection (CAEP) and other federal organizations, such as the Federal Interagency Committee on Aviation Noise (FICAN) [FAA, 2003]. However, since these tools do not contain any economic output, the FAA-AEE does not currently perform any environmental economic analysis. Furthermore, FAA economic analyses are typically unique to each situation.

Through mutual work with ICAO/CAEP, several analytical tools have been considered by the ICAO members. Tools worth noting include the Aviation Emissions and Evaluation of Reduction Options Modeling System (AERO-MS) and the Stratus Consulting Spreadsheet Model (SCSM). They are discussed in more detail in Section 5.2. The main goal of these tools is to analyze the environmental impact of various aspects of air travel and specifically aircraft operations. The environmental economic outputs of these tools, however, are limited. In conjunction with the ICAO participation, common international guidance for the setting of emissions and noise standards for aircraft and aircraft engines was developed. These standards are the basis of FAA's aircraft and engine performance certification standards, established through EPA regulations [FAA, 2005].

5.1.1.1 Regulatory Analysis

Inside the FAA, several offices perform functions pertaining to environmental economic analysis. Specifically, the FAA-AEE develops, recommends, and coordinates national aviation policy relating to environmental and energy matters, including noise and emissions. Generally its economic assessment work is limited to review of potential environmental rulemaking actions and associated economic implications related to domestic issues, including compliance reviews of aircraft noise-related documents pertaining to 14 CFR Parts 150 and 161. Most of the FAA-AEE's environmental economic assessment work pertains to its participation in ICAO's CAEP.

Additionally, the Office of System Architecture and Investment Analysis (ASD) is responsible for the planning, design, formulation, and evaluation of system improvements and interfaces for the National Airspace System. The economic assessment of the Air Traffic Organization's (ATO) regulatory action is conducted by the Office of Aviation Policy and Plans (APO). APO develops policies, goals, and priorities, forecasts future aviation technology and demand, and analyzes the economic impact of regulations. However, regulatory evaluations performed for AEE rely on environmental economic assessments developed through the CAEP process. Such work focuses on the cost of compliance and safety implications of the rulemaking actions in question. All other regulatory evaluations and regulatory impact analyses performed by APO pertain to the cost of compliance and benefits avoided or mitigated from safety (mostly) and operational efficiency issues rather than environmental issues. APO also performs some financial assessments on some projects for the Office of Airports (ARP), which are usually in the form of benefit-cost analyses.

The purpose of the Joint Planning Development Office (JPDO) is to ready the existing air transportation system for the projected increase in demand in support of the Next Generation Air Transportation System (NGATS). Most of the analyses associated with this work are not economic. However, some analyses relate to the operational impacts, including environmental effects and economic implications. These rely heavily on contract support and input from participants involved with NGATS.

Additionally, ARP advises and assists rulemaking actions relating to the certification and capacity of airports. BCA is used to determine the extent to which benefits exceed costs for Airport Capital Improvement Plan (AIP) grants. This work is usually performed by APO, which means that the ARP does not perform economic analyses per se, other than supporting decision-makers in AIP decisions. These BCA are usually integrated with or directly related to Environmental Impact Statements (EIS).

5.1.1.2 Environmental Impact Statements

U.S. Federal law requires an environmental assessment (EA) and environmental impact statement (EIS), or finding of no significant impact, for proposed Federal actions related to airports. Airport project sponsors, the FAA, cooperating agencies, and the public all have roles to play in the environmental assessment process. The National Environmental Policy Act (NEPA) and the Council on Environmental Quality (CEQ) have developed federal regulations for EIS preparation. CEQ 1502.l states that “The primary purpose of an environmental impact statement is to serve as an action-forcing device to insure that the policies and goals defined in the Act are infused into the ongoing programs and actions of the Federal Government. It shall provide full and fair discussion of significant environmental impacts and shall inform decision-makers and the public of the reasonable alternatives which would avoid or minimize adverse impacts or enhance the quality of the human environment.” [CEQ, 1978] Economic analyses, including specific costs and benefits, are taken into account in the preparation of airport project EIS documents.

For example, on January 13, 2005, the Draft Environmental Impact Statement for Washington Dulles International Airport (IAD) was released and hearings were held in the following month. The EIS adheres to a rigid structure and covers a very broad spectrum of environmental issues and concerns. The premise for the proposed projects at IAD is to “allow IAD to safely and efficiently accommodate future activity without incurring unacceptable aircraft operational delay.”

Proposed airport improvements include two new runways and concomitant gate and terminal facilities. Future traffic demand projections out to 2010 derive from the Terminal Area Forecast (TAF). Traffic modeling and airport delay projections are modeled in SIMMOD. The IAD EIS analysis points to unacceptable levels of delay. The study indicates flight delays greater than 5 minutes per flight will exist in 2010, necessitating the airport improvements.

INM, EDMS, and EPA's AERMOD and MOBILE 6.2 models were used in the study. CO, NO_x and O_3 were modeled. Particulate matter was not analyzed because the EDMS database did not contain the appropriate emission factors at that time.

The economic modeling consists of estimates of regional benefits from increased labor through induced jobs, higher business revenues, and a larger tax base. Airport operational benefit from delay savings were extended to air carriers, ($35.25 per **minute**) and passengers ($37.68 per **hour**). No adverse health effects were expected from the no-build scenarios. There was no economic modeling or valuation for health effects.

Another example is the expansion of the Hartsfield-Jackson Atlanta International Airport [FAA, 2002]. Very similar analysis was performed for that EIS, primarily due to federal regulations that specify INM to be used for noise analysis. One exception is the use of a grid noise analysis tool in conjunction with a database of locations of public buildings, such as libraries, schools, parks, and private residences. This allowed the analysis of how many of each would be directly affected by increased noise for each of the considered scenarios. However, no steps were taken to calculate the cost of abatement measures or possible relocation or other impacts. Again, the economic analysis was limited to estimates of regional benefits from increased business revenues, increased labor, and a larger tax base.

Efforts to address aircraft noise and aviation air pollutant emissions issues have advanced largely along independent paths. Although there has been some crossover in recent years, the current level of integration is not sufficient to meet today's needs and future needs [TRB, 2004]. A key requirement for APMT is to address these interdependent effects.

5.1.2 FAA's future analysis needs

The future analysis needs are driven by a desire to improve the decision-making process. This implies taking a step towards developing an environmental benefit-cost analysis capability for aviation, which should establish a new understanding of trade-offs and better interpret risks and guide research agendas.

Sought-after capabilities include the points described by stakeholders during a recent workshop hosted by the Transportation Research Board [TRB, 2005]. The model should allow the following:

- Produce overall benefits and costs to society (welfare economics), as well as record benefits and costs to each party to understand incentives and market responses (distributional analysis).
- Provide full benefit-cost model accounting for differences in global CAEP, regional, national, and local areas.
- Cover benefits and costs to all parties from aircraft manufacturer to society as a whole—an end-to-end approach that accounts for everything, even if all impacts cannot be quantified.

- Record results for each identified user and affected party including: manufacturers, airlines, air navigation service providers, airports, military, General Aviation, passengers and shippers, society impacted, etc. ("balance sheets").
- Account for design constraints of aircraft and engines.
- Assess cost-effectiveness and return on investment of emissions and noise regulations.
- Provide/generate/allow for an analysis of strategies to introduce a policy and alternatives or scenario analysis.
- Have the capability for cost risk exposure and risk analysis.
- Have the ability to conduct sensitivity analysis.

These future analyses have to assess benefits and costs to all affected parties, from aircraft manufacturers, passengers, etc. to society as a whole. Additionally, they have to record benefits and costs to each party to understand incentives and market responses (e.g., benefits of emissions trading) and they have to assess noise and various types of emissions with the ability to consider trade-offs among these, while having the transparency or ability to cross check [Lukachko and Waitz, 2005].

An important overarching goal is the development of superior decision support tools that enable an interdisciplinary approach to assessing aviation environmental impacts and interrelationships. This requires an analysis of noise and emissions interdependencies in both the design and operating contexts. To enable these various analyses, a forecasting module is needed that more accurately predicts future air traffic and demand, including aircraft fleet forecasts [Mavris, 2005]. Such a forecasting module also needs to be compatible with AEDT, due to the similar needs and the envisioned linkage.

The ultimate goal is the ability to address the need of government agencies to assess the consequences of proposed environmental actions and policy decisions in terms of the effects on noise and air pollutant exposure. Additionally, the public needs reliable and clear information on noise and emissions impacts to participate effectively in decision making that could affect health and welfare [TRB, 2004].

5.1.3 Aviation environmental economic analyses performed by others in the United States

Several environmental-economic modeling capabilities exist in the aviation community at large. Costing models seem to be most prevalent. Benefit models and their estimates tend to be controversial due to the difficulty in capturing a benefit and then monetizing its value. Air traffic forecasts are available from aviation manufacturers and associations (Boeing, Airbus, RAA, etc.), as well as the FAA and consulting organizations employed by the FAA (LMI, MITRE, etc.). The models and modeling are not integrated into a complete economic analysis.

In fall 2004, the FAA conducted a survey of existing tools and models relevant to APMT in an attempt to understand capabilities currently in use (presented in TRB AEDT/APMT

Workshop 2005). Of the responses, 17 models or tools were reviewed as well as 8 studies for application to APMT. In addition, 14 traffic simulation models were reviewed for relevancy to APMT. U.S. models and internationally sponsored models were included in the reviews.

The majority of the models address either noise or emissions. The Campbell Hill Cost Model falls into this category, but is still an important model to take into consideration. It uses a detailed fleet database, which is compatible with the MAGENTA global noise model to assess the costs of CAEP/5 noise policy scenarios. Its detailed database, as well as treatment of costs, including factors such as phase outs, recertification, freighter conversion, and aircraft disposition as scrap or in the used market for failure to meet policy requirements, make it an important reference.

Two models did, however, address both noise and emissions. The JPDO is working with National Aeronautics and Space Administration (NASA) and Metron Aviation Inc. in the use of the Airspace Concepts Evaluation System (ACES) to consider both noise and emissions generation (though not with an economic perspective). The modeling provides a local, regional, and national estimate of the simultaneous distribution of noise and emissions. A second model, Multi-Attribute Impact Pathway Analysis (MAIPA), currently under development at MIT, also addresses noise and emission trade-offs for aviation, but is unique in that it incorporates monetization of benefits. The MAIPA research is designed to answer the question: if we can greatly reduce one kind of pollutant by accepting increases in another, should we? The MAIPA model applies probabilistic monetary values to health and noise exposure impact using hedonic wage (statistical value of life) and real estate analysis.

Another model of interest is the Tracking and Analysis Framework (TAF) developed for the Department of Energy (DOE) at Argonne National Laboratory and applied by Resources for the Future (RFF) to analysis for the state of Maryland. While the research was not applied to aviation, it does model SO_2 and NO_x health, soils-aquatic, and visibility effects, and provides monetized estimates of the benefits from reduction and trade-offs between them. The framework and techniques for monetizing are relevant to APMT development.

5.2 International

5.2.1 ICAO-CAEP environmental economic analyses

In its role representing ICAO on issues of the environmental impact of aviation and environmental policy, CAEP has conducted extensive analysis for purposes of setting specific international standards on aircraft emissions and noise exposure. CAEP assists in the formulation of new policy and aircraft noise and emission standards by undertaking a variety of studies.

CAEP now recognizes economic analysis as the most appropriate method for evaluating noise and emissions standards. During the fifth and sixth formal meetings (CAEP/5 and CAEP/6), the Committee had access to economic analysis information when making recommendations to the ICAO Council on increases to noise and NO_x stringency increases, respectively. Summaries of the economic analyses along with the recommendations are documented in the formal reports of the meeting. These publications may be purchased from ICAO. The CAEP Forecasting and Economic Support Group (FESG) is comprised of numerous economics and forecasting experts consisting of members and observers, who, when needed, participate in various task groups to conduct much of the economic analysis. CAEP analysis is built upon three components: forecasts of future aircraft traffic and passenger demand, stringency cost impacts on manufacturers and air carriers, and benefits as measured by reduced exposure to noise and reduced levels of emissions. The working groups employ several models for forecasting and estimating costs and benefits. The Boeing Global Emissions Model (GEM) and SAGE incorporate forecasts of aircraft operations while estimating emissions on a global scale. FESG develops traffic and fleet forecasts from ICAO and aircraft and engine manufacturer forecasts. AERO-MS has been used for cost and benefit assessments of market-based options related to climate change policy proposals (CO2 emissions). MAGENTA and EDMS have been used for noise-impacted population and emissions inventories, respectively. Estimates of benefits from increased stringency are measured in terms of pollution reduction (NO_x, particulates, etc.) and counts of persons exposed to noise levels. The future streams of these measures estimated over the forecast period are then discounted to a present value based on discount rates prescribed by OMB and other guidance. Monetization, or a representation of the cash value of the benefits, is not used.

Analyses are separated by examination of emissions or noise. Joint analysis of CO_2 and NO_x has been conducted; however, trade-off analysis between them has not. The inability to monetize has led to the use of surrogate benefit measures for the future reductions in harm associated with the different policy solutions (pounds of emissions or number of people impacted by noise). Since benefits were not monetized, the conclusions drawn regarding different policy options may be invalid because the environmental benefits are non-linearly related to reductions in the surrogate measures. Further, the CEA techniques that have been employed do not allow a determination of whether a policy option produces as a net gain or net loss for society.

CAEP has recently begun investigating market-based options (MBO’s) as another method of limiting or reducing aviation emissions. From an economic perspective, MBO’s are regarded as having potential cost-savings to society by allowing firms to determine how they will meet environmental standards, set not at the individual engine or airframe level, but rather at some level that characterizes net harm (i.e. a total emissions level or total noise exposure level).

For example, the paper CAEP/5-Information Paper #9 considers applications of MBO’s for reduction of CO_2 from aviation. The focus is on airline cost implications and does not address supply side effects, nor macroeconomic impacts. AERO-MS is also not integrated into the study. CAEP is aware that MBO research deserves greater attention and is encouraging member and observer states to play an active role.

In the following section we consider in more detail specific tools that were developed through CAEP and its participating members.

5.2.1.1 AERO-MS

AERO-MS has been in use since 1994. Available through CAEP and the Dutch Civil Aviation Authority, the sponsors of its development, the AERO-MS model consists of 8 modules:

1. aircraft technology,
2. air transport demand and traffic levels,
3. operating costs,
4. direct economic impact (global),
5. economy-wide impacts (Netherlands only),
6. emissions (from flights and other sources),
7. concentrations of emissions, and
8. global warming effects.

AERO-MS represents a comprehensive approach to economic modeling of emissions policy in aviation—though it does not address placing an economic value on the changes in emissions associated with policies. It uses a projection framework that leaves demand and traffic proportional to a base year (1992). The modules interact with each other so that as direct costs to airlines are calculated, fares are adjusted in response; traffic levels respond to fare changes, emissions levels respond to the change in traffic levels, and so on. AERO-MS modelers acknowledge that the model "has to be up-dated, or made more flexible." It appears that the economy-wide impact model would require significant development to apply it to cases other than the Netherlands. This would involve adding a module based on input-output tables from other countries or regions around the world.

5.2.1.2 SCSM

Stratus Consulting Spreadsheet Model (SCSM) was designed to augment the capabilities of the AERO-MS model in the evaluation of potential CO_2 reduction measures. SCSM designers recognized the need for better modeling of the implications of abatement costs on supply side technologies and operations and the responding effect on demand.

The SCSM model developers sought to estimate how increased costs resulting from greater stringency requirements would change demand for airline travel and, through an iterative process, estimate the least-cost solution to a CO_2 emission target. SCSM supply side technology response options are:

- **Early retirement of aircraft** – if it is more cost effective to do so
- **Re-engining** – engine replacement offering lower fuel burn
- **Engine retrofit and upgrade** – conducted during maintenance overhaul to improve fuel efficiency
- **Winglets** – a fuel burn cost saving estimate exists for each aircraft type, aircraft already fitted with winglets are assumed to be offered improved versions.

- **Polishing vs. painting A/C shell** – less weight when not painted and better fuel burn
- **Reducing engine and airframe maintenance intervals** – replaced by more frequent major overhauls to correct performance deterioration
- **More regular maintenance to correct aerodynamic deterioration**
- **Reducing fuel tankering** – carrying less fuel improves fuel burn

SCSM takes the supply side cost increases and estimates demand side responses on a global scale. Using a global air travel demand elasticity of -0.7, the model estimates the global response in flights and revenue passenger kilometers, passenger and cargo demand, fuel use, CO_2 emissions, and the effect on consumer surplus.

5.2.2 ICAO-CAEP's future analysis needs

The CAEP Work Program developed by CAEP/5 in January 2001 sets forth areas of future study needs. The ICAO Assembly, which meets every three years, endorses action in areas of future study based on development work conducted to date. The document referred to as Resolution A33-7 contains the actions agreed to by the Assembly.

The work program offers two broad areas for continued research, improving study capabilities in aircraft engine emissions and noise abatement. It lays out areas where better data, enhanced research techniques, and improved understanding of knowledge among stakeholders should be pursued. CAEP also recognizes the value of refinements to existing analysis capabilities.

A33-7 contains eight appendices in which the ICAO Assembly "welcomes," "requests," "encourages," and "urges" the council and contracting states to continue analysis in the areas of:

- Development of standards, recommended practice and procedures and/or guidance material relating to the quality of the environment
- Policies and programs based on a "balanced approach" to aircraft noise management
- Phase-out of subsonic jet aircraft that exceed the noise levels in Volume I Annex 16
- Local noise-related operating restrictions at airports
- Land-use planning and management
- Supersonic aircraft – the problem of sonic boom
- Environmental impact of civil aviation on the atmosphere
- Market-based measures regarding aircraft engine emissions

As the environmental steward for aviation, the Assembly's focus is on fostering the working relationships and cooperative spirit necessary to stimulate global solutions.

Analysis needs coming from CAEP/6 discussions contained in Statement from the ICAO to the Twentieth Session of the UNFCCC Subsidiary Body for Scientific and Technologic Advice Bonn, June 2004 indicate CAEP analysis needs will also include:

- Reducing emissions at the source – the NOx levels adopted in 1999 will be further reduced by 12% in 2008
- Reducing fuel burn through improved operational measures – stemming from better operational efficiency from improved CNS/ATM technology
- Analyzing the use of market-based measures – voluntary measures, emission related levies and emissions trading targeting primarily CO_2 emissions
- Collecting information relevant to all market-based measures – determining whether or not airlines from developing countries are exempted
- Improving data, quantification, and analysis capability for inventories and factors contributing to them

Attendees at the TRB workshop on AEDT/APMT held in Washington, DC in January 2005 identified, in addition to those previously outlined, the following future economic analysis needs of the CAEP:

- A methodology for monetizing benefits
- Noise/emission tradeoff analysis capability
- Local and global trends
- Cost data and certification timeframe and impact on costs
- Aircraft owner (general aviation, airlines, and business jets) business economic modeling
- Land use issues
- Contrail atmospheric impact, climate change

5.2.3 Aviation environmental economic analyses performed by others internationally

In recognition of the fact that across the different European countries and transportation modes interest in balancing pricing and the real societal marginal cost of transportation exists, the Eurocontrol Experimental Centre (EEC) has undertaken a review of institutional studies on environmental economics. It is suggested that the long term objective is to move in the direction of user pays and polluter pays principles when developing policy and committing public funds.

European studies provide estimates of external costs among the various modes of transportation and the factors included in those costs. Aviation's portion of noise, pollution, and climate change are among them. These studies draw upon revealed preference, stated preference, and alternative cost (damage cost) methods. The effort, with varying success and applicability, strives to monetize costs and benefits.

Another area under review in Eurocontrol is the effect of Air Traffic Management (ATM) and inefficient routing as it contributes to environmental degradation. A project is underway to develop indicators to measure the impact of the Air Traffic Control system on the environment. These indicators allow the impact of changes to the ATM system to be observed over time in terms of distance flown and fuel burn, as well as airline and environmental costs. They are used by the Eurocontrol Performance Review Commission for its annual performance assessment of air traffic management in Europe.

There has also been some work conducted in valuing aircraft noise. Two such research efforts include analysis by Morrell and Lu (2000), which considers hedonic pricing relative to noise levels, and Schipper (1996), where a statistical link between the Noise Depreciation Index (NDI) and property values is tested across several similar analyses.

6 APMT STAKEHOLDERS

In developing the requirements for APMT, it is important to consider the entities that will be potentially impacted by a regulatory policy decision in the aviation environmental field. For complete economic analysis, the consideration of benefits and costs associated with these entities, either direct or part of an aggregation, should be included. These entities can be grouped as follows:

- Local/regional community:
    - Individuals living near airports
    - Individuals living in a region economically affected from collocation with air transportation services
- Users of air transportation services:
    - Passengers
    - Freight services
- Providers of air transportation services:
    - Airlines
    - Cargo companies
    - Airports
- Manufacturers:
    - Airframe and engine companies
    - OEM and part suppliers
- Global community:
    - People impacted by air transportation
    - Nations
    - Other transportation modes

The needs and viewpoints of each entity are represented by organizations in various forms, e.g. community groups, local and national governments, regulatory agencies (FAA, EPA, etc.), and international organizations. Some of these organizations are responsible for regulating the entities involved to achieve the best outcome. An economic analysis tool such as APMT will be useful to guide these organizations in designing effective policies.

Ideally, such an economic analysis tool should possess the flexibility to allow application at various scopes: local, regional, national, or global. However, different scopes of analysis imply different levels of cost and benefit aggregations, which will be difficult to accommodate simultaneously. The capabilities the tool must have, at least in the early development stage, were determined by prioritizing potential uses and users of the tool.

Initially, it is envisioned that ICAO-CAEP and governments in various capacities will be the primary users of APMT, and as such their needs will be addressed as a priority in APMT development. However, in the later stages of development, the user base is expected to become more diverse and cover a wider range of organizations with various interests and needs. These potential users are listed below together with short descriptions of their scope of needs.

Primary users:

- ICAO-CAEP. APMT will be developed to meet the needs of the CAEP process, especially to assist CAEP in analyzing economic trade-off scenarios involving various policy options.
- Government. Various government agencies, including regulatory bodies (e.g. FAA, Department of Transportation) and research organizations or consortiums (e.g. JPDO), will find APMT useful. For regulatory bodies, APMT can support the analyses of environmental policies. For research organizations or consortiums, APMT can support policy-related research and should be useful to determine future research directions.

Secondary users:

- Manufacturers. Results of analysis using APMT may be useful for aircraft and engine manufacturers to determine research and development priorities in light of potential future environmental policy and regulations.
- Airlines. APMT may be a useful resource to assist in planning for fleet, operations, and future investment strategies in the context of potential future environmental policies.
- Airports. Understanding trade-offs of environmental benefit and cost impacts associated with various technology, operations, policy, and market scenarios will allow airport authorities to make better-informed decisions regarding improvements to environmental quality around an airport.
- Academia. APMT can serve as a valuable tool for various intellectual exercises to support research on the impact of aviation on the environment.

- Think tanks and non governmental organizations.
- Consultants. Government agencies, airlines, airports, and community groups frequently rely on specialized consulting agencies that provide environmental and economic analysis services.

There are other potential APMT users, such as the public, including home owners and neighborhood organizations, other non-governmental entities, and financial organizations, but the ones listed above are considered the key users and will be taken into consideration in the APMT development process.

7 APMT REQUIREMENTS

This section describes the requirements for APMT. In Section 7.1, we provide an overview of the requirements and recommended functionality, both near-term and longer-term. Section 7.2 then includes a list of detailed functional requirements for APMT. Requirements related to the process of developing and using APMT are listed in Section 7.3.

7.1 Overview of APMT requirements

This section provides an overview of the requirements for APMT. To every extent possible, these requirements were constructed directly from national and international guidance on performing analysis of environmental regulations and policies. We consulted many documents, but drew most heavily from the EPA *Guidelines for Preparing Economic Analyses* [EPA, 2000], OMB Circular A-4, *Best Practices for Regulatory Analysis* [OMB, 2003], the UK HM Treasury *Green Book on Appraisal and Evaluation in Central Government* [UK HM Treasury, 2003], UK Cabinet Office, Better Regulation Executive *Regulatory Impact Assessment Guidance* [UK BRE, 2005], OECD *The economic appraisal of environmental projects and policies – A practical guide* [OECD, 1995], Transport Canada *Guide to Benefit Cost Analysis in Transport Canada* [TC, 1994], WHO *Air Quality Guidelines for Europe* [WHO, 2000a], Kopp, Krupnick, Toman, Resources for the Future, *Cost Benefit Analysis and Regulatory Reform: An Assessment of the Science of the Art*. [RFF, 1997], Krupnick, Ostro, and Bull *Peer Review of the Methodology of Cost-Benefit Analysis of the Clean Air for Europe Programme*, [Krupnick et al., 2004], and from the Clean Air for Europe (CAFÉ) Programme *Methodology for the Cost-Benefit Analysis for CAFÉ Vol. 1* [CAFÉ 2005].

In this light, we begin with a quotation from the introduction from the EPA document, setting the broad objectives for APMT:

> *Underlying this exercise is the recognition that a thorough and careful economic analysis is an important component in designing sound environmental policies. Preparing high quality economic analyses can greatly enhance the effectiveness of environmental policies by providing policy makers with the ability to systematically assess the consequences of regulatory and non-regulatory actions. An economic analysis can describe the implications of policy alternatives not just*

for economic efficiency, but for the magnitude and distribution of an array of impacts. Economic analyses also serve as a mechanism for organizing information carefully. Thus, even when data are insufficient to support particular types of economic analyses, the conceptual scoping exercise may provide useful insights.

Thus, economic analyses should always acknowledge and characterize important uncertainties that arise throughout the analysis. Economic analyses should clearly state the judgments and decisions associated with these uncertainties and should identify the implications of these choices. When assumptions are necessary in order to carry out the analysis, the reasons for those assumptions must be stated explicitly and clearly. Further, economic analyses of environmental policies should be flexible enough to be tailored to the specific circumstances of a particular policy, and to incorporate new information and advances in the theory and practice of environmental policy analysis. [EPA, 2000, p1]

7.1.1 Recommended functionality for APMT

As described in Section 3, environmental economic analyses can be divided into three categories: cost-effectiveness analysis (CEA), benefit-cost analysis (BCA), and distributional analysis (DA). Economic impact analysis and equity analysis are subsets of the last category, DA. Each of these three types of analysis is designed to answer a different question. Across these three categories and within these three categories, tools are required that are at different levels of scope and fidelity, depending on the scope of the analysis and data availability. In Table 4, we outline the types of analysis and the tools within each category. The acronyms and numbers will serve as a key for the list of detailed functional requirements contained in Section 7.2. Also referenced in the table and later in Sections 7.2 and 7.3 are categories of potentially impacted entities, including:

a) Producers in the primary market (airlines, airports and manufacturers); producers in secondary and related markets (e.g. travel and tourism, aerospace suppliers, etc.); producers in other markets (anything else);
b) Consumers of goods and recipients of environmental harm as characterized by different geographical and other qualities such as airline customers, local communities, global communities, and specially-defined subpopulations for equity analyses (e.g. children, small businesses, Native Americans, etc.); and
c) Governments, both as regulators of flows in the economy and as producers in the economy (through provision of services).

In Table 5, we present a timeline for development of APMT capabilities. It defines the recommended timeframes for development and use as well as the geographical and economic scope for analyses performed using APMT. Broadly, in considering the information presented in Section 7, the current practice within ICAO-CAEP focuses on cost-effectiveness analysis (CEA.1 and CEA.2), although some recent analyses of market-based options have employed partial-equilibrium models of producers in the primary markets (BCA.2.1). APMT must be capable of reproducing these capabilities and then expanding beyond them. The primary environmental impacts that must be addressed with these tools are local air quality, community noise, and climate change.

Because of the immediacy of upcoming global decisions and the need to adequately inform these decisions, the highest priority for the geographical and economic scope for all of these analyses should be global and regional (or national). Thereafter, focused studies over smaller geographical areas and economies could be pursued (e.g. within a single airport community).

To respond to the near-term FAA needs, we recommend that the FAA start immediately to develop the capabilities for an expanded cost-effectiveness analysis that would be operational within 1-3 years. The analysis should accept a range of environmental performance indicators from AEDT (e.g. number of people living within DNL 65dB, kg NOx, kg fuel burn, etc.) and enable a first assessment of indirect environmental effects that policy options in one domain may produce in another domain (e.g. the effects of noise stringency on NOx levels). The FAA should also immediately start to develop the capabilities for benefit-cost analysis within the primary aviation market to include monetization of benefits (BCA.1.1) and quasi-equilibrium modeling of the consumers and producers in the primary market (BCA.2.1), since benefit-cost analysis should ultimately supplant the near-term reliance on cost-effectiveness analysis. Due to limited availability of data, it is expected that this capability would be developed first for application within the U.S. (within 1-3 years), and then expanded internationally through partnerships and collaborations (3-6 years).

Thereafter, to address longer-term needs (3-8 years), APMT development should focus on expanding these capabilities, first to include the addition of indirect and induced cost assessments (BCA.2.2). This expansion should be done through developing a general equilibrium model, which would also allow distributional analyses (DA.1 and DA.2). Then, as environmental economics research continues to mature, it will be necessary to include indirect and induced benefits assessment (BCA.1.2) to provide a complete capability for BCA and DA. However, indirect and induced benefits assessment is not an immediate priority.

Table 4. Outline of functional requirements

<table>
<tr><th>Types of Analysis</th><th>Question Answered</th><th>Tools of Analysis</th></tr>
<tr><td rowspan="2">Cost-Effectiveness Analysis (CEA)</td><td rowspan="2">“Given several options for addressing an environmental problem which option provides the greatest change in a surrogate for environmental impact per unit of cost?”</td><td>CEA.1 Benefits Assessment:
Requires some measure of system performance that serves as a surrogate for the full monetized environmental benefit value (e.g. kg of NOx per year or # of people living in DNL 55dB).</td></tr>
<tr><td>CEA.2 Costs evaluation:
Considers the changes in capital and operating costs in primary markets and potentially in enforcement costs (e.g. FESG spreadsheet that calculates manufacturer and airline marginal costs in response to a policy scenario) with appropriate discounting.</td></tr>
<tr><td rowspan="2">Benefit-Cost Analysis (BCA)</td><td rowspan="2">“Relative to a well-defined baseline scenario, to what degree does a policy scenario improve economic efficiency?”</td><td>BCA.1 Social Benefits Assessment:
Requires methods to convert system performance to both health and welfare impacts (e.g. # of asthma cases, premature mortality, etc.) and other benefits (e.g. operational efficiency) in comparable ways (usually monetary values since this is also comparable to the social costs metric) with appropriate discounting.
BCA.1.1 Revealed preference methods, stated preference methods and out-of-pocket expenditures—and hybrids thereof for assessing direct effects (e.g. hospitalization, lost wages, housing devaluation)
BCA.1.2 General economic models (e.g. input-output models for marginal sensitivities, and models for reaching a new optimization point) for assessing indirect benefits (e.g. changes in household consumption patterns in response to environmental damages) and induced benefits (any multiplier effects after the consumption patterns change – e.g. people get sick more often and they buy less paper so it impacts the paper industry). These techniques are currently a research activity.</td></tr>
<tr><td>BCA.2 Social Costs Assessment:
BCA.2.1 Partial equilibrium models to evaluate costs in the primary market (e.g. supply = airlines and demand = travelers and freight). This allows consideration of market-based options, of command and control options, etc.
BCA.2.2 General equilibrium models to assess the indirect and induced effects (e.g. how do changes in production and consumption in the aviation industry lead to changes in production and consumption in other parts of the economy).</td></tr>
<tr><td rowspan="3">Distributional Analysis (DA)</td><td rowspan="3">“Which entities pay the costs and receive the benefits?”</td><td>DA General equilibrium models, national or global in scope, are required to assess who pays and who receives the benefits.</td></tr>
<tr><td>DA.1 Economic Impacts Analysis:
Determines the costs and benefits that accrue to various potentially impacted entities.</td></tr>
<tr><td>DA.2 Equity Assessments:
Applies impacts assessments for specific subpopulations (e.g. for example those considered to be disadvantaged, such as small businesses, Native Americans, etc.)</td></tr>
</table>

Table 5. APMT Requirements Timeline

Development Time Frame	Title	Scope	Capabilities
Years 1-3	APMT v1 Enhanced Cost-Effectiveness Capability	National/Global	Cost-effectiveness analysis that replicates existing CAEP practice, but uses inputs from AEDT to provide integrated assessment of noise, local air quality and climate variables (CEA.1 and CEA.2)
Years 1-6	APMT v2 Benefit-Cost Assessment Capability	National/Global	Add monetized benefits and partial equilibrium modeling of the primary markets (BCA.1.1 and BCA.2.1) enabling limited distributional assessments (DA.1 and DA.2)
Years 3-8	APMT v3 Benefit-Cost Assessment Capability with Indirect and Induced Costs	National/Global	Indirect and induced cost assessment using a general equilibrium model (BCA.2.2) to enable more complete distributional assessments (DA.1 and DA.2)
Years 6-8+	APMT v4 Benefit-Cost Assessment Capability with Indirect and Induced Costs and Benefits	National/Global	Addition of indirect and induced benefits
Years 6-8+	APMT-Local v1	Local/Regional	Perform benefit-cost assessment on local/regional scale

7.2 APMT Functional Requirements

Below we list the functional requirements for APMT in categories corresponding to those shown in Table 4. Items in italics are quoted from the national and international guidance on analyzing environmental policies.

7.2.1 CEA Cost-Effectiveness Analysis

CEA.1 Benefits Assessment

APMT must be capable of reproducing existing capabilities for cost-effectiveness analysis as employed within ICAO-CAEP using surrogate measures of monetized environmental benefits such as kg-NO_x, number of people living within 55dB DNL, etc.

CEA.2 Cost Assessment

APMT must be capable of reproducing existing capabilities for cost analysis for the primary market (e.g. compliance costs for manufacturers and airlines) as employed within ICAO-CAEP. Where warranted, the existing methods should be improved.

Cost-effectiveness is a criterion for judging the most efficient way of performing a given task. Whatever other decision rule is applied, the chosen method should normally also be the most efficient, that is, the cheapest, way of meeting the objectives of the project. Where the project has no measurable (quantifiable) benefits, or where an environmental goal has been sent by national authorities or in an international agreement, the cost-effectiveness criterion is the main one to apply. It is very simple, consisting of calculating all the costs, both discounting the resulting stream to obtain a present value for costs. This procedure is repeated for the main alternative ways of carrying out the project, and the one with the lowest present value is chosen. Note that this criterion assumes that all the alternatives being compared can carry out the project equally well. If, on the other hand, there are quality differences in the service being supplied the basis of comparison is invalid. [OECD, 1995, p32]

7.2.2 BCA Benefit-Cost Analysis

BCA.1 Social Benefits Assessment

APMT must be capable of making estimates of health improvements and other environmental benefits for a policy alternative relative to a well-defined baseline scenario.

Using estimates of health and other risk-reduction effects provided by risk assessors, benefits analyses apply a variety of economic methodologies to estimate the value of anticipated health improvements and other sources of environmental benefits. [EPA, 2000, p20]

The relevant costs and benefits to government and society of all options should be valued, and the net benefits or costs calculated…Wider social and environmental costs and benefits for which there is no market price also need to be brought into any assessment. They will often be more difficult to assess but are often important and should not be ignored simply because they cannot easily be costed. [UK HM Treasury, 2003, p19]

BCA.1.1 Monetization of Benefits

APMT must be capable of monetizing the benefits through best available techniques including revealed preference methods, stated preference methods, out-of-pocket expenditures, and hybrids of these methods.

At its roots, benefits analysis develops monetary values to inform the policy making process. These values are important because they allow decision makers to directly compare costs and benefits using the same measure (i.e., dollars). [EPA, p59]

To the extent feasible and warranted by their contribution to the results, as many of the effects of a policy as possible should be monetized. This enhances the value of the conclusions to policy makers weighing the many, often disparate consequences of different policy options and alternatives. [EPA, 2000, p176]

One challenge facing analysts of environmental policies is the lack of a market for most environmental improvements. Because "cleaner air" or "cleaner water" is not normally bought or sold, market data are generally not available for benefit valuation. Economists have therefore developed other methods for eliciting values for these types of effects. These methods rely either on information from the markets for related goods (revealed preference methods) or on direct information on people's preferences (stated preference methods). [EPA, 2000, p62]

The general rule is that benefits should be valued unless it is clearly not practicable to do so. [UK HM Treasury, 2003, p19]

The quantification of potential social, health or environmental impacts normally requires an alternative approach to valuation. Techniques to establish money values for this type of non-market impact generally involve the inference of a price, through either a revealed preference or stated preference approach.. [UK HM Treasury, 2003, p57]

So for placing a value on: the environment—you could use surveys that show people's willingness to pay (how much people would pay for a clean river, fresh air or a national park) or their willingness to accept (how much people would be prepared to accept in compensation for suffering from pollution); life/health—you could use estimates of the value of a statistical life, or the cost to the national health system of treating the illness. [UK BRE 2005]

Recommended methods for monetizing benefits are shown in Table 6.

Table 6. Recommended methods for monetizing benefits [OECD, 1995, p43]

Impact	Valuation methods
Productivity	*Market valuation of physical effects (MVPE)* *Avertive behaviour (AB)* *Defensive expenditure (DE)* *Replacement cost (RC)*
Health	*Human capital (HC) or cost of illness (COI)* *Contingent valuation (CVM)* *Avertive behaviour* *Defensive expenditure*
Amenity	*Contingent valuation* *Travel cost (TCM)* *Hedonic property method (HPM)*
Existence values	*Contingent valuation*

BCA.1.1.2 Benefit categories to be considered

APMT should be capable of assessing mortality, morbidity, amenity, ecological and mobility benefits to the extent they are determined to be significant and to the extent that data are available to assess them.

Table 7. Examples of benefit categories [adapted from EPA, 2000, p67]

Benefit Category	Examples
Mortality	Reduced risk of: cancer fatality, acute fatality
Morbidity	Reduced risk of asthma incidence, cancer, nausea
Amenity	Noise exposure, visibility
Ecological	Global warming productive impact, agricultural yield; recreation opportunities; non-use (existence and bequest value)
Mobility	Increased operational efficiency

BCA 1.1.3 Effect-by-Effect Benefits Analysis

APMT should adopt an effect-by-effect approach to considering the environmental impacts of noise, climate, and local air quality as well as for different benefit categories within these three impact categories.

A given policy may produce many different benefits, but it is seldom possible to obtain a single, comprehensive value estimate for the collection of effects. This will often leave analysts with no alternative but to address these effects individually, aggregating values to generate an estimate of the total benefits of a policy alternative. [EPA, 2000, p59]

The most widely used approach for estimating the benefits of a policy option is to evaluate separately the major effects of a given policy and then sum these individual measures to arrive at total benefits. [EPA, 2000, p62]

The general effect-by-effect approach for assessing the benefits of environmental policies includes three components:
1) Identify potentially affected benefit categories by developing an inventory of the physical effects that may be averted by the policies.
2) Quantify significant physical effects to the extent possible working with managers, risk assessors, ecologists physical scientists, and other experts.
3) Estimate the values of these effects using studies that focus on the effects of concern or transferring estimates from studies of similar impacts. [EPA, 2000, pp62-63]

BCA.1.1.4 Adoption of existing benefits studies and flexibility to incorporate new work.

APMT should use existing techniques and data to assess benefits, but should also be flexible enough to allow the results of new studies to be incorporated when appropriate.

EPA has developed extensive guidance on the assessment of human health and ecological risks and analysts should refer to those documents and the offices responsible for their production and implementation for further information. [EPA, 2000, p64]

The technique chosen will depend on the individual circumstances, and should be judged on a case-by-case basis. As a general rule, revealed preference methods are fairly reliable, and should be used where the relevant information can be inferred. However, they cannot estimate the value placed on an asset by people who make no direct use of it. In these circumstances, stated preference methods may be helpful. In some cases, it will be appropriate to use both techniques together, for example, to check the consistency of results. [UK HM Treasury, 2003, p58]

Consider using more than one method to estimate benefits. [EPA, 2000, p65]

It is important to keep in mind that research on all of these methods is ongoing, sometimes at a rapid pace. [EPA, 2000, p72]

BCA.1.2 Indirect and Induced Benefits Assessment

Assessment of indirect and induced benefits is not a near-term priority for APMT. However, as techniques for addressing these benefits become more mature, they should be considered for inclusion in APMT.

The most appropriate methods for measuring the societal gain from indirect benefits of environmental health interventions (such as productivity) need to be decided. [WHO, 2000b]

BCA.2 Social Costs Assessment

APMT should be capable of estimating the total social costs of a policy alternative relative to a well-defined baseline scenario.

The total social cost is the sum of the opportunity costs incurred by society because of a new regulatory policy; the opportunity costs are the value of the goods and services lost by society resulting from the use of resources to comply with and implement the regulation, and from reductions in output. These costs, however, do not take into account any of the health, environmental, safety, or other benefits which offset the social welfare costs. [EPA, 2000, pp113-114]

BCA.2.0.1 Cost categories to be considered

APMT should be capable of assessing the following cost categories to the extent they are determined to be significant and to the extent that data and methods are available to assess them.

The five basic components of total social costs are listed here in the general order of relative ease of estimation, and hence inclusion, in most social cost analyses of environmental policies. They include:

<u>Real-resource compliance costs</u>: *These direct costs are the principal component of total social costs and are associated with: (1) purchasing, installing, and operating new pollution control equipment, (2) changing the production process by using different inputs or different mixtures of inputs, or (3) capturing the waste products and selling or reusing them. (The last two options can actually result in negative compliance costs.) These real-resource costs should also include unpriced resources that have opportunity costs associated with them, such as unpaid labor diverted from other productive uses, and extra administrative costs associated with compliance. However, the pre-tax compliance costs do not include any transfers, such as emissions taxes, licensing fees, or subsidies (which are included in the firm's private costs).*

<u>Government regulatory costs:</u> *These include the monitoring, administrative, and enforcement costs associated with new regulations. This also includes the cost of setting up a new market when incentive based regulations are established, such as tradable permits.*

<u>Social welfare losses</u>: *These are the losses in consumer and producer surpluses*

associated with the rise in the price (or decreases in the output) of goods and services that occurs as a result of an environmental policy.

<u>*Transitional costs:*</u> *These include the value of resources that are displaced because of regulation-induced reductions in production, and the private real-resource costs of reallocating those resources. Offsetting these costs, in theory, are regulation-induced increases in resource use in both primary and related markets (e.g., more workers and equipment are needed for pollution control). Indirect costs: These other costs include the adverse effects policies may have on product quality, productivity, innovation, and changes in markets indirectly affected by the environmental policy, all of which may have impacts on net levels of measured consumer and producer surplus.*

<u>*Indirect costs:*</u> *These other costs include the adverse effects policies may have on product quality, productivity, innovation, and changes in markets indirectly affected by the environmental policy, all of which may have impacts on net levels of measured consumer and producer surplus.* [EPA, 2000, pp113-114]

BCA 2.1 Direct Primary Market Social Costs Assessment

APMT should be capable of assessing the direct social costs in the primary commercial aviation market (airlines, airplane and engine manufacturers, airports, passengers and freight shippers) using partial-equilibrium models.

In general, the social cost of a policy can be measured exclusively by changes that occur in the markets directly targeted by a policy, as long as significant net changes in social welfare are not generated in indirectly affected markets. If price changes in other markets generate both gainers and losers among the producers and consumers, then they may offset each other in a social cost analysis as transfers. However, if there are strong reasons to believe that conditions in other related markets might generate important net social welfare consequences, these should be examined. If a policy indirectly increases or decreases the quantity of a good that is consumed, whose production or consumption involves an externality, then this results in net social welfare effects that may be worth considering when calculating total social costs (and benefits). [EPA, 2000, p124]

"Partial" equilibrium refers to the fact that the supply and demand functions are modeled for just one or a few isolated markets and that conditions in other markets are assumed either to be unaffected by a policy or unimportant for social cost estimation. [EPA, 2000, p125]

In most cases, a conventional partial equilibrium framework comparing the pre-policy baseline with the expected results of a new environmental policy will suffice for an economic analysis. [EPA, 2000, p125]

Even transitional effects that result in short-run social costs, such as premature capital equipment retirement and relatively brief spells of involuntary unemployment, can be modeled and estimated using this framework. Thus, the approach offers a theoretically sound, if limited, method for conceptualizing the consequences of an environmental policy and measuring their social costs. [EPA, 2000, p126]

BCA 2.2 Indirect and Induced Social Costs Assessment

Although it is not a near-term requirement, in the longer-term APMT should be capable of assessing the indirect and induced social costs of a policy alternative using a general equilibrium model.

Although the use of a partial equilibrium or multi-market model may be appropriate when policies are likely to affect a limited number of markets, they are not able to capture interactions between a large number of sectors. Many environmental policies, such as energy taxes, can be expected to impact a large number of sectors both directly where the policy is applied, and indirectly through spillover and feedback effects on those and other sectors. A strength of general equilibrium models is their ability to account consistently for the linkages between all sectors of the economy. [EPA, 2000, pp126-127]

Other possible components of social costs, such as effects on product quality, productivity, innovation, and market structure, can require fairly complex dynamic models to quantify. Although most individual regulatory policies will not have such dramatic effects, these costs can be quite significant in certain instances, such as when a policy's requirements delay industrial projects or affect new product development. Such policy effects have implications for future social costs but are difficult to measure and express in social cost terms. However, an effort should be made to qualitatively describe these factors and look at approaches that can quantify these effects when data and resources can support this level of detailed analysis of social costs. [EPA, 2000, p122]

7.2.3 DA Distributional Analysis

DA.1 Economic Impact Analysis and DA.2 Equity Assessments

Although it is not a near-term priority, for the longer-term, APMT should include the capability for distributional assessments using a general equilibrium model.

Any distributional effects identified should be explicitly stated and quantified as far as possible. At a minimum, this requires appraisers to identify how the costs and benefits accrue to different groups in society. If, for example, the costs of a government action fall largely upon one ethnic group this impact should be detailed in the appraisal. [UK HM Treasury, 2003, p91]

The conceptually appropriate framework for assessing all the impacts of an environmental regulation is an economic model of general equilibrium. The starting point of such a model is to define the allocation of resources and interrelationships for an entire economy with all its diverse components (households, firms, government). Potential regulatory alternatives are then modeled as economic changes that move the economy from a state of equilibrium absent the regulation to a new state of equilibrium with the regulation in effect. The differences between the old and new states—measured as changes in prices, quantities produced and consumed, income and other economic quantities—can be used to characterize the net welfare changes for each affected group identified in the model. [EPA, 2000, p19]

Some forms of regulation can be quite narrow in the range of responses they engender. These regulations tend to be tightly focused on target activities (e.g., selected industrial sectors) and do not spill over into sectors that are not direct targets. However, depending on the nature of the activities to be regulated and the magnitude of the responses required, secondary effects of the policy can be felt beyond the direct target of the policy. When secondary effects are de minimis, they can be ignored in a cost study, and economic techniques of partial equilibrium analysis may be properly applied. However, when secondary effects are thought to be large, a general equilibrium analysis is called for…Unfortunately, there is no easy way to tell when a policy will require a full general equilibrium analysis and when a partial analysis will do. Most likely, regulations that affect highly integrated sectors of the economy, such as sectors that produce widely used intermediate products (like energy), will require general equilibrium analyses. Policies that generate large direct costs may also call for a general equilibrium approach. Other than these rather crude rules of thumb, little direct guidance can be provided. However, because a partial analysis is just a special case of a general equilibrium analysis, agencies can err on the side of caution and conduct a general equilibrium analysis, even if it turns out that a partial analysis would have been sufficient. Inasmuch as a general equilibrium analysis can be relatively expensive, agencies should develop and maintain a computable-general-equilibrium (CGE) model for regulatory purposes, allowing general equilibrium analyses to be routinely and cheaply performed. [RFF, 1997, pp27-28]

7.2.4 GE General Functional Requirements

GE.1 APMT-AEDT Interface, Input/Output and Consistency

APMT must incorporate tools including AEDT, EDS and the FESG fleet forecasts. A harmonized system architecture must be implemented to ensure that consistent assumptions are applied within all components of the APMT tool suite for both the baseline and policy scenarios being analyzed.

GE.2 Uncertainty

APMT should employ techniques that enable uncertainty to be explicitly represented and communicated as part of the policy analysis process. To the extent possible, quantitative estimates of uncertainty should be provided. If the uncertainty is a function of the interval of time over which the analysis is focused, this should be made explicit.

Uncertainty is inherent in economic analyses, particularly those associated with environmental benefits for which there are no existing markets. The issue for the analyst is not how to avoid uncertainty, but how to account for it and present useful conclusions to those making policy decisions. Treatment of uncertainty, therefore, should be considered part of the communication process between analysts and policy makers. Transparency and clarity of presentation are the guiding principles for assessing and describing uncertainty in economic analyses. Although the extent to which uncertainty is *treated and presented will vary according to the specific needs of the economic analysis, some general minimum requirements apply to most economic analyses. In assessing and presenting uncertainty the analyst should, if feasible: present outcomes or conclusions based on expected or most plausible values; provide descriptions of all known key assumptions, biases, and omissions; perform sensitivity analysis on key assumptions; and justify the assumptions used in the sensitivity analysis.* [EPA, 2000, p27]

Explicitly address uncertainty. [EPA, 2000, p66]

It is essential to consider how future uncertainties can affect the choice between options. [UK HM Treasury, 2003, p32]

Probabilistic methods, including Monte Carlo analysis, can be particularly useful because they explicitly characterize analytical uncertainty and variability. However, these methods can be difficult to implement, often requiring more data than are available to the analyst. [EPA, 2000, p28]

Monte Carlo analysis is a risk modelling technique that presents both the range, as well as the expected value, of the collective impact of various risks. It is useful when there are many variables with significant uncertainties. [UK HM Treasury, 2003, p33]

Confidence intervals are generally useful to describe the uncertainty associated with particular variables. When data are available to estimate confidence intervals they can serve to characterize the precision of estimates and to bound the values used in sensitivity analysis. [EPA, 2000, p28]

The model for estimating benefits and costs (as well as any effectiveness measures used for cost-effectiveness analysis) should be capable of fully addressing statistical uncertainty, in the sense of capturing standard errors around all key parameters and promulgating these distributions through the analysis to yield probability distributions of benefits, costs, effectiveness measures and net benefits. [Krupnick, et al., 2004, p42]

GE.3 Sensitivity Analyses

APMT must be capable of sensitivity analyses for key variables

The dynamic aspects of market and consumer behavior, and the many motivations leading to change, can make it more difficult to attribute economic costs and benefits to specific regulations. Looking at the sensitivity of the outcome of the analysis to these conditions and assumptions will be useful. [EPA, 2000, p22]

Alternatively, when the number of conceivable options is essentially infinite, the analysis should at least span the range of possibilities. [EPA, 2000, p26]

Sensitivity analysis is fundamental to appraisal. It is used to test the vulnerability of options to unavoidable future uncertainties. Spurious accuracy should be avoided, and it is essential to consider how conclusions may alter, given the likely range of values that key variables may take. Therefore, the need for sensitivity analysis should always be considered, and, in practice, dispensed with only in exceptional cases. [UK HM Treasury, 2003, p32]

It is always useful to see how net benefit estimates or other outputs of the economic analysis change with assumptions about input parameters. Sensitivity analysis provides a systematic method for making these determinations. [EPA, 2000, p28]

GE.4 Policy Baselines

APMT must be capable of representing different policy baselines.

An economic analysis of a policy or regulation compares "the world with the policy or regulation" (the policy scenario) with "the world absent the policy or regulation" (the baseline scenario). Impacts of policies or regulations are measured by the resulting differences between these two scenarios. [EPA, 2000, p21]

Specification of baseline conditions can have profound influence on the measurement and interpretation of analytic results. [EPA, 2000, p21]

GE.5 Time Span for Analysis

APMT must be capable of making assessments over different time spans.

Primary considerations in determining the time horizon of the analysis will be the time span of the physical effects that drive the benefits estimates, and capital investment cycles associated with environmental expenditures. [EPA, 2000, p23]

In some cases the benefits of a policy will be expected to increase over time. Some analyses must therefore look far enough into the future to assure that benefits are not substantially underestimated. For example, suppose a policy that would greatly reduce greenhouse gas emissions were being proposed. [EPA, 2000, p23]

GE.6 Discounting

APMT must be capable of incorporating different values for discount rates as well as different methods for discounting.

The costs and benefits of many environmental policies are frequently paid and received at different points over the course of sometimes long time horizons.

As a result, benefit-cost and related analyses that are key components of EPA's policy development and evaluation process must describe future effects in terms that help present day policy makers choose appropriate approaches for environmental protection. One common method for doing so is called discounting, which is the process whereby the values of future effects are adjusted to render them comparable to the values placed on current consumption, costs, and benefits, reflecting the fact that a given amount of future consumption is worth less than the same amount of consumption today.

Despite the relative simplicity of the discounting concept, choosing a discount rate has been one of the most contentious and controversial aspects of EPA's economic analyses of environmental policies. [EPA, 2000, p33]

Thus, for government projects and policies that require large initial outlays or that have *long delays before benefits are realized, the selection of the discount rate can be a major factor in determining whether the net present value is positive.* [EPA, 2000, p36]

Economic analyses should present a sensitivity analysis of alternative discount rates, including discounting at two to three percent and seven percent as in the intra-generational case, as well as scenarios using rates in the interval one-half to three percent as prescribed by optimal growth models. The discussion of the sensitivity analysis should include appropriate caveats regarding the state of the literature with respect to discounting for very long time horizons. [EPA, 2000, p52]

It is important to understand that the appropriate discount rate depends entirely on the point of view taken in the analysis and that this point of view must be stated explicitly. If, for example, the point of view is that of a particular group of people, then the appropriate discount rate would be one that reflects the time preference of the members of that group. Research shows that if the members of the reference group are poor, the discount rate that reflects their time preference is likely to be high - they will highly value immediate benefits because they have basic needs that are unmet. The cost of borrowing might not approximate their discount rate (unlike the case of a business corporation) if their access to credit is limited or distorted. [Treasury Board of Canada Secretariat, 1998, 5.5]

GE.6.1 Discounting Non-Monetized Effects

APMT should provide an option for discounting of non-monetized effects when this is appropriate (e.g. for some types of cost-effectiveness analysis).

In many cases, quantitative information on the time streams of physical effects is available and these effects are measured in terms of human health consequences and ecosystem damages that correspond to endpoints that are normally monetized. If so, then these non-monetized benefits ought to be discounted if monetized costs and benefits are discounted. [EPA, 2000, p53]

Choosing not to discount non-monetized benefits can have perverse consequences. [EPA, 2000, p53]

While there are many cases in which non-monetized benefits can and should be discounted along with all of the other costs and benefits of environmental policies, there are others in which benefits are not monetized for reasons that pose more significant problems for discounting. Specifically, sometimes the available measures of benefits are very poor proxies for ultimate damages, making it difficult to discount them correctly. When an analysis stops far short of the physical effects that are good proxies for damages, the relationship between harms and emissions—or other relevant physical measures— might be poorly understood. [EPA, 2000, p54]

GE.7 Alternate assessments of risk

APMT should provide the capability to represent alternate perceptions of risk and scientific assessments of risk.

Lay perceptions of risk may differ significantly from scientific assessments of the same *risk, and an extensive literature has developed on the topic. Because individuals respond according to their own risk perceptions, it is important for the analyst to be attentive to situations where there is an obvious divergence in these two measures. In such cases, analysts should consider evaluating policy options under both sets of information, clearly stating the basis for economic value estimates used or developed in their analysis.* [EPA, 2000, p29]

Monetary valuation of control actions and of health and environmental effects may be different in concept and vary substantially from country to country. In addition to variations in assessing costs, the relative value of benefit categories, such as benefits to health or building materials, will vary. Thus, the result of comparing costs and benefits in two areas with otherwise similar conditions may differ significantly. [WHO, 2000a, p50]

GE.8 Exogenous Technological Change

APMT should enable consideration of different rates of exogenous technological change.

Economic analysis of environmental policies may be affected by the pace of exogenous technological change. In principal, accounting for this can either increase or decrease marginal and total abatement costs, depending on the direction of change. Generally, however, the expectation is that accounting for exogenous technological change would decrease estimated abatement costs. Recent analyses have indicated that even for mature technologies the magnitude of this effect can be large. [EPA, 2000, p30]

7.3 Development and Use Requirements for APMT

This section contains a list of good practices and guidelines that are not related specifically to the functionality of the APMT modeling tools but rather to the process by which it is developed and used.

DU.1 Full-disclosure and transparency

During the process of developing and using APMT, processes must be adopted to ensure full disclosure and transparency. In situations where components of the tool are derived from proprietary data, the rationale and process for doing so must be clearly described. It may also be necessary to establish processes (e.g. independent third party reviews) to build confidence in the models.

Analysis of the risks, benefits, and costs associated with regulation must be guided by the principles of full disclosure and transparency. Data, models, inferences, and assumptions should be identified and evaluated explicitly, together with adequate justifications of choices made, and assessments of the effects of these choices on the analysis. The existence of plausible alternative models or assumptions, and their implications, should be identified. In the absence of adequate valid data, properly identified assumptions are necessary for conducting an assessment. [OMB, 2003, Introduction]

In addition, the methods used to conduct the analysis should be clearly described, and the *limitations and caveats associated with the analysis should be discussed. Transparency of the analysis is most important.* [WHO, 2000a, p51]

DU.2 Thoroughness and Practicality

The process of developing and using APMT should strike an appropriate balance between thoroughness and practicality.

Analysis of the risks, benefits, and costs associated with regulation inevitably also involves uncertainties and requires informed professional judgments. There should be balance between thoroughness of analysis and practical limits to the agency's capacity to carry out analysis. The amount of analysis (whether scientific, statistical, or economic) that a particular issue requires depends on the need for more thorough analysis because of the importance and complexity of the issue, the need for expedition, the nature of the statutory language and the extent of statutory discretion, and the sensitivity of net benefits to the choice of regulatory alternatives. [OMB, 2003, Introduction]

DU.3 Engagement of Stakeholders

Throughout the process of developing and using APMT, national and international stakeholders should be regularly consulted and offered the opportunity to provide input.

As you design, execute, and write your regulatory analysis, you should seek out the opinions of those who will be affected by the regulation as well as the views of those individuals and organizations who may not be affected but have special knowledge or insight into the regulatory issues. Consultation can be useful in ensuring that your analysis addresses all of the relevant issues and that you have access to all pertinent data. Early consultation can be especially helpful. You should not limit consultation to the final stages of your analytical efforts. [OMB, 2003, p3]

DU.4 Treatment of Non-Quantified Impacts

The development and use of APMT should include a discussion of non-quantified impacts.

A complete regulatory analysis includes a discussion of non-quantified as well as quantified benefits and costs. A non-quantified outcome is a benefit or cost that has not been quantified or monetized in the analysis. When there are important non-monetary values at stake, you should also identify them in your analysis so policymakers can compare them with the monetary benefits and costs. When your analysis is complete, you should present a summary of the benefit and cost estimates for each alternative, including the qualitative and non-monetized factors affected by the rule, so that readers can evaluate them. [OMB, 2003, p3]

Describe qualitatively effects that cannot be quantified. It will not be possible to quantify all of the significant physical impacts for all policies. [EPA, 2000, p64]

There will be certain benefits and costs which remain unquantified, either because *evaluation methodologies are not reliable or because the scale of the study does not justify the effort to measure them. In this latter case, the project analyst should attempt to estimate the likely value. As a minimum, options should be ranked in terms of the estimated magnitude of the unquantified effects.*[TC, 1994, p17]

The most common technique used to compare both unvalued costs and benefits is weighting and scoring (sometimes called multi-criteria analysis).The basic approach to weighting and scoring involves assigning weights to criteria, and then scoring options in terms of how well they perform against those weighted criteria. The weighted scores are then summed, and these sums can be used to rank options.An even simpler method is to list the required performance criteria (sometimes called 'critical success factors'), and assess options in terms of whether they meet them or not. [UK HM Treasury, 2003, p35]

DU.5 Professional Judgment

APMT must be developed and used with due consideration for the complexities and challenges of environmental economic analysis. Professional judgment will be required to effectively respond to a broad range of analysis needs.

You will find that you cannot conduct a good regulatory analysis according to a formula. Conducting high-quality analysis requires competent professional judgment. Different regulations may call for different emphases in the analysis, depending on the nature and complexity of the regulatory issues and the sensitivity of the benefit and cost estimates to the key assumptions. [OMB, 2003, p3]

DU.6 Documentation of APMT Development

A formal process should be implemented to document the development of APMT including the assumptions, data sources and references.

A good analysis provides specific references to all sources of data, appendices with documentation of models (where necessary), and the results of formal sensitivity and other uncertainty analyses. [OMB, 2003, p3]

DU.7 Assessment and Improvement

A formal process for assessing and improving APMT should be implemented once it is developed.

Constant advances in theoretical and empirical research in the field of environmental economics will require that the Agency reexamine the EA Guidelines on a continual basis. The Agency will again enlist experts in the field of environmental economics and engage in an open review of the scientific basis of the document when it is reevaluated in the future. [EPA, 2000, preface]

REFERENCES

AERO (2002) Presidential Commission on the Future of the U.S. Aerospace Industry, *Final Report of the Presidential Commission on the Future of the U.S. Aerospace Industry*. Arlington, VA, 2002. URL: http://www.aia-aerospace.org/issues/ commission/commission_report.pdf [accessed July 2004].

Aldy, J. E. and W. K. Viscusi (2004). Age Variations In Workers' Value Of A Statistical Life. *Harvard John M. Olin Discussion Paper*, No. 468.

Anderson, R. C. and P. Kobrin (2000). *Regulatory Economic Analysis at the EPA*. Resource Consulting Associates.

Argonne National Laboratory (ANL), Decision and Information Sciences Division. 1996. *Tracking and Analysis Framework (TAF) Model Documentation and User's Guide.* [http://lumina.com/taf/taflist/dltaf/TAF.pdf]

Callan, S.J., and J.M. Thomas (2000). *Environmental Economics and Management; Theory Policy, and Applications*. Harcourt Brace, Orlando.

Clean Air for Europe (CAFÉ) Programme (2005). Methodology for the Cost-Benefit Analysis for CAFÉ Vol. 1, 2 , and 3. *Service Contract for Carrying Out Cost-Benefit Analysis of Air Quality Related Issues, in particular in the CAFÉ programme.*

Council on Environmental Quality (CEQ) (1978) *CEQ regulations part 1502 – Environmental Impact Statement.* URL: http://ceq.eh.doe.gov/nepa/regs/ceq/1502.htm [accessed June 2005]

Diamond, P.A. and J. A. Hausman (1994). Contingent Valuation: Is Some Number Better than No Number? *Journal of Economic Perspectives,* Vol. 8, pp45-64.

Economics for the Environment Consultancy Ltd. (EEC) (2002). *Populating the Environmental Evaluation Reference Inventory: 40 European valuation studies.* URL: http://europa.eu.int/comm/environment/enveco/others/population_of_the_environmental_valuation_reference_index.pdf [accessed June 2005]

FAA (2001). *Final environmental impact statement for 9,000-foot fifth runway and associated projects: Hartsfield Atlanta International Airport*. City of Atlanta, Fulton and Clayton Counties, Georgia, Dept. of Transportation. College Park, Ga.

FAA (2003). *National Aviation Research Plan*.

FAA (2004). *Federal Aviation Administration Flight Plan 2004-2008*.

FAA (2005). *Aviation & Emissions: A Primer*.

FAA Office of Aviation Policy and Plans (FAA-APO) (1998). *Economic Analysis of Investment and Regulatory Decisions*.

Harrington, W., R. D. Morganstern, and P. Nelson (1999). On the Accuracy of Regulatory Cost Estimates. *Resources for the Future Discussion Paper,* No. 99-18.

Holland, M. and P. Watkiss (BeTa version E1.02a). *Benefits Table Database: Estimates of the marginal external costs of air pollution in Europe.* URL: http://europa.eu.int/comm/environment/enveco/air/betaec02a.pdf [accessed June 2005]

International Civil Aviation Organization (ICAO) (2004). *Strategic Objectives of ICAO for 2005-2010.*

International Civil Aviation Organization (ICAO) (2001). *Resolution A33-7: Consolidated Statement of Continuing ICAO Policies and Practices Related to Environmental Protection.*

Joint Planning and Development Office (JPDO) (2004). *Next Generation Air Transportation System Integrated Plan*.

Kenkel, D. 2000. "Using Estimates of the Value of Statistical Life in Evaluating Regulatory Effects." *Proceedings of Valuing the Health Benefits of Food Safety,* September 14-15, 2000. United States Department of Agriculture Miscellaneous Publication Number 1570, April 2001.

Kolstad, C. D. (2000). *Environmental Economics*. Oxford University Press, New York.

Kopp, R.J., A.J. Kuprick, and M. Toman. (1997). Cost-Benefit Analysis and Regulatory Reform: An Assessment of the Science and the Art. *Resources for the Future Discussion Paper*, No. 97-19.

Krupnick, A. J. (2004*). Valuing Health Outcomes: Policy Choices and Technical Issues.* RFF Report.

Krupnick, A., B. Ostro, and K. Bull (2004). *Peer Review of the Methodology of Cost-Benefit Analysis of the Clean Air for Europe Programme.* Paper prepared for European Commission Environment Directorate General.

Lukachko, S. P. and I. A. Waitz (2005). Economic perspectives on representing risks in aviation environmental policy analysis and discussion of relevant literature, *TRB AEDT/APMT Workshop*. Washington D.C.

Mankiw , N.G. (2004). *Principles of Economics*, Third Edition. Thomson South-Western, Mason, Ohio.

Mavris, D. (2005). Formulation of an Integrating Framework for the Aviation environmental Portfolio Management Tool. *TRB AEDT/APMT Workshop*. Washington D.C.

Morrell, P. and C. H.-Y. Lu (2000). Aircraft Noise Social Cost and Charge Mechanisms – A Case Study of Amsterdam Airport Schipol. *Transportation Research*, vol5, no.4, pp305-320.

National Environmental Technology Center (NetCen) for the European Commission. 2002. Benefits Table Database (BeTa). [http://europa.eu.int/comm/environment/enveco/air/betaec02a.pdf]

National Research Council (NRC) (2003). Securing the Future of U.S. Air Transportation: A System in Peril. Committee on Aeronautics Research and Technology for Vision 2050, Aeronautics and Space Engineering Board, Washington, DC, 2003, URL: http://books.nap.edu/catalog/10815.html, [accessed July 2004].

Nordhaus, W. D. and Z. Yang. 1996. A Regional Dynamic General-Equilibrium Model of Alternative Climate-Change Strategies. *The American Economic Review*. 86 (4): 741-765.

Organisation for Economic Co-operation and Development (OECD) (1995). *The economic appraisal of environmental projects and policies - A practical guide.*

Phaneuf, D. J. and V. K. Smith (2004). Recreation Demand Models. Prepared for *Handbook of Environmental Economics*. K. Mäler and J. Vincent, Editors. Forthcoming.

Portney, P. R. (1994). The Contingent Valuation Debate: Why Economists Should Care. *Journal of Economic Perspectives,* vol. 8, pp3-17.

Russell, C.S. (2001). *Applying Economics to the Environment*. Oxford University Press, New York.

Schipper, Y. J. J. (1996). On the Valuation of Aircraft Noise: A Meta-Analysis. *European Regional Science Association 36th European Congress*. Zurich, Switzerland.

Shogren, J. F. and T. D. Crocker (1999). Risk and Its Consequences. *Journal of Environmental Economics and Management,* 37, pp44-51

Transport Canada (TC) (1998). *Guide to Benefit Cost Analysis in Transport Canada.* TP11875E.

Transportation Research Board (TRB) (2004). *Critical Issues in Aviation and the Environment*. TRB Circular Number E-C069.

Transportation Research Board (TRB) (2005). *LETTER REPORT: Workshop #3, FAA Aviation Environmental Design Tool (AEDT) and Aviation Portfolio Management Tool (APMT)*. URL: http://trb.org/publications/reports/aedt_may_2005.pdf [accessed July, 2005].

UK Cabinet Office, Better Regulation Executive (UK BRE) (2005). *Regulatory Impact Assessment Guidance.*

UK HM Treasury (2003). *The Green Book. Appraisal and Evaluation in Central Government.*

United States Environmental Protection Agency (EPA) (2000). *Guidelines for Preparing Economic Analyses*.

United States Environmental Protection Agency (EPA) (2002). *The Benefits of Reducing Nitrate Contamination in Private Domestic Wells Under CAFO Regulatory Options*.

United States Food and Drug Administration (FDA). 1999. "Food Labeling and Trans Fatty Acids in Nutrition Labeling, Nutrient Content Claims, and Health Claims; Proposed Rule." Federal Register, November 17, 1999.

United States Office of Management and Budget (OMB) (1992). *Circular A-94: Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs*.

United States Office of Management and Budget (OMB) (2003). *Circular A-4: Regulatory Analysis*.

World Health Organization (WHO) (2000a). Air Quality Guidelines for Europe. *WHO Regional Publications, European Series, No. 91.*

World Health Organization (WHO) (2000b). *Considerations in Evaluating the Cost Effectiveness of Environmental Health Interventions.* Prepared by Guy Hutton. WHO/SDE/WSH/00.10.