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Development of Indicators to Assess Economic Vulnerabilities to Changes in Ecosystem Services: Case Study of Counties in Maryland, USA

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ABSTRACT / We develop indicators showing the relative environmental burdens that human activities place on locales for a given level of economic benefits. The main purpose is to develop tools that allow us to examine the potential vulnerabilities within economies to changes in resource conditions. The indicators of pollution emission or resource consumption per job can be used to identify potential challenges to resource and industry managers and to compare areas in terms of their ability to adapt to change. For example, if a large number of area jobs are dependent on abundant water, this indicates a vulnerability to a reduction in water availability for industrial use. We develop a case study for 23 counties and 1 city in Maryland to examine the usefulness and limitations of the indicators. Our case study demonstrates that the indicators provide an informative view into patterns of local economic activity and use of an area's environmental goods and services. In contrast to patterns for total environmental burdens (e.g., total SO_2 emissions) that are typically reported, the rates of environmental burden per job are not simply correlated with high or low economic output. Thus, the indicators represent distinct patterns of environmental burdens per job that reflect reliance on environmental services. The indicators have some limitations when used at this fine scale because they can misrepresent conditions in counties in which economic sectors are dominated by one or a few businesses. For this reason, the indicators are best used as a regional screening tool.

Many indicator systems have been developed to examine risks to natural systems and the services they generate, yet most regional environmental assessments examine the costs of resource use in terms of damages to resources or human health without examining the variety of forces that drive people to use resources as they do (e.g., US EPA 2003a, Noss 1990). Such assessments omit discussion of the benefits people derive from levels of economic activity, perhaps because these benefits seem obvious whereas the risks are typically indirect and indistinct. Because of this past focus on damages in isolation from benefits, environmental assessments typically provide useful information on impairments but do not allow a land-use manager to weigh the costs and benefits of resource management decisions in a common framework.

KEY WORDS: Environmental economic indicators; Vulnerability assessment; Life-cycle analysis; Resource consumption; Pollution emissions

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Although policymakers routinely seek out information on the benefits of using natural resources and the potential harms from doing so, that information typically comes from different sources and can be difficult to compare to environmental damages due to disparate data types, units of measure, and scales of analysis. The difficulty of comparing economic values to environmental indicators can cause some information to be overlooked or poorly integrated.

A large literature exists in environmental economics that attempts to overcome the mixed units problem by characterizing environmental impacts in dollar terms (e.g., Smith 1996) so that they can be directly compared to economic benefits. However, the results are seldom used for regional natural resources management for many reasons. For one, the studies that assign dollar values to ecosystem services can be controversial (Diamond and Hausman 1994, Shabman and Stephenson

2000), in part, because tools are available to assess a relatively small subset of environmental benefits generated from ecosystems (King and Mazotta 2001). In addition, the most accepted economic tools for assessing values of natural resources (e.g., revealed preference studies) are not intended for use at the regional scale because the values they assign are highly dependent on context at a given location and cannot be easily generalized to the region (Bockstael and others 2000). The studies are also time-consuming and costly to conduct. Because of the difficulty of assigning dollars to environmental services, many government agencies continue to rely on a mix of indicators and monetary values as a means to assess policy tradeoffs (Ribaudo and others 2001, Woodley and others 1999).

We have seen a variety of indicator systems that include both environmental and economic indicators but have only seen ratios of benefits to costs evaluated in relatively narrow terms, such as systems that compare habitat benefits or wetland functions to costs of restoration (Burks-Copes and others 2002). Developing methods to compare other types of negative and positive aspects of resource use decisions using net benefits or cost efficiency should assist in resource use decision making.

Through this work, we compare the efficiency of ecosystem service use in terms of economic benefits derived. In addition, we develop an understanding of the dominant economic structure within a region and reveal which resources are tightly bound to the economy. By considering signs of stress on ecosystem services in addition to our measures of environmental burdens per economic benefits, managers may gain insights into what level of resource protection is desirable given both environmental and economic considerations.

Our goal with the indicators is that they be used to examine potential economic vulnerabilities to changes in resource quality or quantity. The questions we aim to address are:

1. How do areas compare in terms of the economic benefits they derive in exchange for the environmental burdens imposed by economic activities?
2. How can indicators of *burden per benefit* ratios be used to assess vulnerabilities arising from the links between the economy and the local natural resources? This paper focuses largely on the techniques of the first goal in order to forward future analysis of the second goal. Our measure of economic benefits is number of jobs created. We did not put any quality measures on the jobs such as wage levels, but these could be added in future analyses. The indicators of environmental burden per job that we derive here must be combined with other measures of natural resource condition to evaluate vulnerabilities, although we discuss potential applications.

The burden per benefit indicators we create are not equivalent to damage estimates, for several reasons. First, these indicators are meant to complement and not replace measures of the total quantities of resources used or pollution emitted within regions because the totals are clearly more important in many types of risk analysis, such as health-related impacts (e.g., Dockery and others 1993). Second, specific characteristics of a pollution source or sink, such as location with respect to dominant wind direction, characteristics of water bodies, location of susceptible populations, existing pollutant levels, and other factors will determine the actual risks associated with pollutant emissions. Furthermore, the pollution generated by a business may not be experienced primarily within its home county. Transportation industries, for example, may release pollutants wherever vehicles travel rather than within the home county. Nevertheless, these county-by-county rates of pollutant emitted or resource used per level of economic activity do serve to demonstrate relative dependencies on particular ecosystem goods and services such as the pollution-mitigating capabilities of a region and, therefore, reveal potential economic risks from changes in resource conditions and environmental management requirements.

By examining indicators of rates of environmental burden per unit of economic activity in areas where resources are being stressed, we expect the indicators to reveal both opportunities and limitations to resource management. Because of the mix of particular types of industries, some county economies will produce more jobs for a given level of resource used or pollution emitted. By comparing the likely environmental burdens per job within an industrial sector, these indicators illustrate differences in relative environmental cost per level of economic benefit among counties, which may be useful when examining how scarce resources should be managed. For example, a growing county that finds a particular ecosystem service is being stressed, such as air pollution assimilation, and finds a relatively high rate of air emissions per job among local businesses, may choose to target its tax incentives in order to attract new businesses with low air pollution per job ratios to ‘‘rebalance’’ their local mix of industries. An understanding of the average ratios for various industries would allow a county to

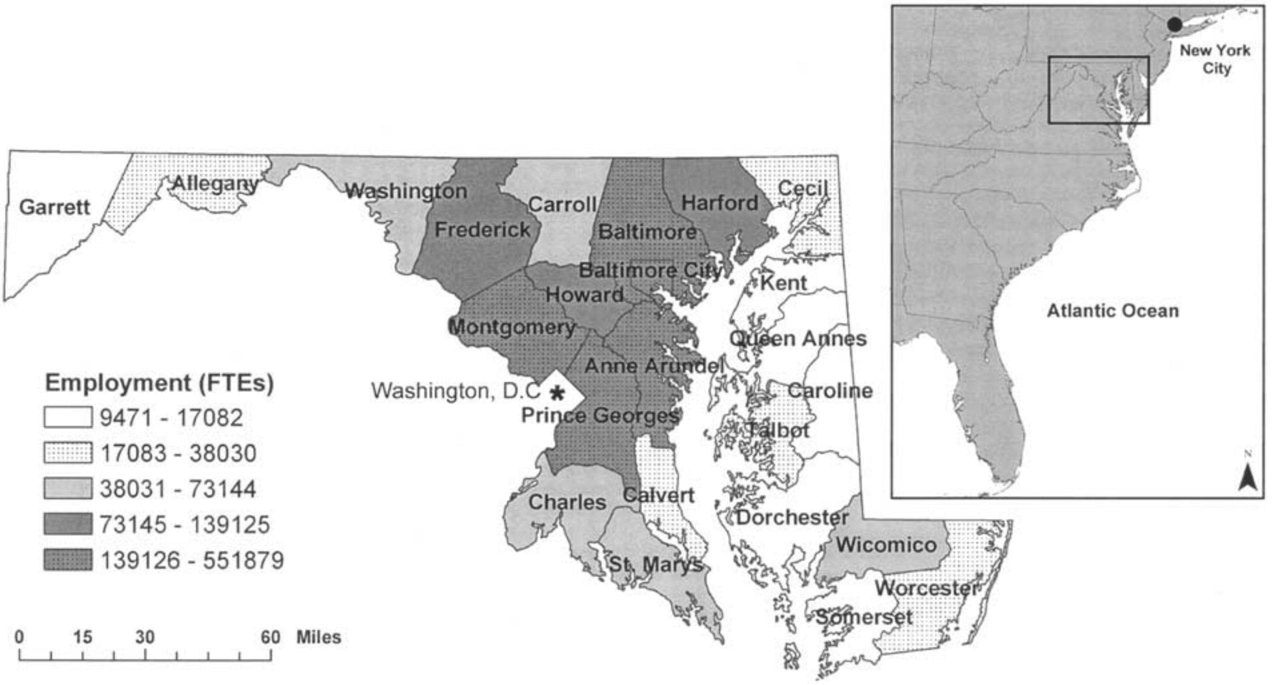

Figure 1. Total employment in Maryland counties, with location map. FTEs, full-time equivalents.

better assess incoming industries in terms of whether they are likely to further stress a vulnerable resource.

Various factors can contribute to a relatively high environmental burden per job within a county. An industry is not necessarily producing excessive pollution because it produces a great deal of pollution per level of output. Instead, the nature of an industry may be such that a high pollution emission rate is considered normal, or even efficient. Specific industries are able to control emissions or rates of resource use in a variety of ways, and thus can deviate greatly from the average values used here.

Developing Indicators for a Regional Scale Assessment

This analysis is part of a coordinated study to provide regional scale information useful for policy analysis (see US EPA Regional Vulnerability Assessment for the mid-Atlantic Region at www.epa.gov/reva). A regional scale approach is an important component of any examination of ecological condition and the associated ecological services on which economies rely, because it can provide information about broad patterns generated by the accumulation of decisions made on a fine scale. One of the general impediments to performing regional assessments is a lack of consistent data across broad spatial areas. Thus, in our analysis, we are testing the quality of indicators that can be developed for the county scale using national databases that are consistent across broad regions.

We chose Maryland (Figure 1) for an initial test of our methods because it is a small state, yet its counties exhibit a fairly broad range of economic characteristics. Our familiarity with the state allowed us to evaluate the indicator results for consistency with known conditions across the state. Our goal with the case study was to evaluate whether available information could be used to create reliable indicators of the strength of the links between economic activity and ecological services, such as waste assimilation.

Methods

To develop indicators for comparing the relative amounts of pollution generated and resources used for a given level of economic output or job created, we relied on two related datasets: economic input–output tables and environmental life-cycle tables. The input–output tables represent the economic structure of regions in terms of the total economic output of and purchases made by businesses within the region. Input–output tables are produced by the US Bureau of Economic Analysis but are supplemented and maintained by researchers and private firms [e.g., Minnesota IMPLAN Group (MIG) 1999]. Similar to the economic input–output tables, life-cycle tables represent pollution generated and resources used in the production and delivery of goods and services within industries. The values are represented as average rates per output by economic sector. Data on pollution emissions and resource use rates are collected by various federal agencies and have been put into a standard format by university researchers [Carnegie Mellon University (CMU) 2000]. Combining these datasets allows us to evaluate and compare pollution produced or resources used within a county for a given economic structure.

Regional Economic Models

The method of using input–output analysis to examine economic structure was developed specifically to examine economic issues at a regional scale (Leontief 1986). At the core of the method are standardized matrices that represent the economy as activity within and between sectors. The database we used contains 528 detailed economic sectors (MIG 1999) based on data from the 1997 economic census and other sources. The matrix values represent typical purchases within an industry, and any given industry can be linked to 100 or more other industries through purchases, thereby producing a complex web of relationships. The database also includes information on the number of jobs created by sector and other economic characteristics for each of the 528 detailed industrial sectors. The matrices can be used to evaluate the current structure of the economy or to predict changes in economies (employment, income, etc.) in response to a change in activity in some specific sector of the economy.

Resource Use and Pollution Emissions Characterization

To calculate the environmental burdens imposed by economic activity, we use a type of life-cycle analysis that relates resource use and pollution emissions within an industry (Table 1) to the level of production. This partial life-cycle approach estimates resource inputs and waste outputs for the entire supply chain used in the production of a good or service. By contrast, a full life-cycle analysis includes these same resource inputs and waste outputs, but adds to them the inputs and outputs associated with the use or consumption of the final good or service, such as the resources used to dispose of packaging.

The calculated total amount of a resource used or waste generated by an industry (e.g., billions of gallons of water used by a manufacturing industry) includes three types of effects: direct, indirect, and induced. Direct environmental burdens result from a sector's withdrawals from and/or emissions to the natural environment (e.g., natural gas withdrawals or toxic emissions). Indirect environmental burdens result from purchases that a sector makes from other sectors that also withdraw natural materials from and emit pollutants to the environment as part of their production. Finally, the income generated as a result of the direct and indirect activities induces households to make purchases that generate new environmental burdens, and this consumption continues to contribute to induced burdens as subsequent effects play out in the economy (e.g., as household demand for a good rises, production in that industry increases, generating more purchases of inputs).

Limitations of the Methods

Input–output techniques are in widespread use, but are criticized on several methodological fronts. A primary concern is that the relationship between inputs to production and outputs is assumed to be a linear function based on average industry conditions. With linear functions, each additional unit of production is assumed to result in the same additional unit of input demanded or pollution output. Thus, the data will not account for nonlinearities in production functions or allow differences between companies within a sector. Furthermore, any new technology that changes the production function is not immediately incorporated. When examining small regions such as counties, functions based on average conditions are more likely to misrepresent the particular industries present than estimates for the country as a whole. Although these limitations of input–output techniques are significant, the technique remains in widespread use because to increase the quality of the calculations would require costly investments in research that would only marginally improve the data quality and would lead to inconsistencies between regions.

Data Sources

Data for the analysis of environmental burdens came from two databases that are aggregations of data from a variety of sources. Most of the data came from researchers at CMU and their partners who developed the Economic Input–Output Life Cycle Assessment (EIOLCA) website (CMU 2000). They provided us with direct coefficients of withdrawals, emissions, and other environmental factors by Bureau of Economic Analysis (BEA) industrial sector number. The other database was the Typical Pollutant Concentration (TPC) matrix developed at the National Oceanic and Atmospheric Administration (Pacheco and others 1993), which provides typical concentrations of pollutants in effluents

Table 1. Environmental burdens evaluated for regional economies[a]

Environmental variables	Abbreviation
Energy (terajoules)	ENER
Electricity (million kilowatt hours)	ELEC
External costs: high, medium, and low estimates (millions of 1992 dollars)	XT (H, M, L)
Consumption of fuels (metric tons)	
Motor gasoline	MGAS
Liquified petroleum gas	LGAS
Light fuel oil	LFO
Heavy fuel oil	HFO
Bituminous coal	BCO
Fertilizer purchases (millions of 1992 dollars)	
Conventional pollutants to air (metric tons)	
Sulfur dioxide	SO_2
Carbon monoxide	CO
Nitrogen dioxide	NO_2
Volatile organic compounds	VOC
Lead particulate emissions	PB
Particulate matter less than 10 microns	PM_{10}
Global warming gases produced (metric tons CO_2 equivalent)	
Carbon dioxide	GCO_2
Methane	GCH_4
Nitrous oxide	GN_2O
Chlorofluorocarbons	GCFC
Weighted index of all four gases	GWP
RCRA hazardous waste (metric tons)	
Generated	RCRG
Managed	RCRM
Shipped	RCRS
Toxic releases (metric tons) unweighted and weighted by toxicity	
Air releases	TRI3 / ET3
Water releases	TRI4 / ET4
Land releases	TRI5 / ET5
Underground releases	TRI6 / ET6
Total releases	TRI7 / ET7
Publicly owned treatment works (POTW)	TRI8 / ET8P
Offsite transfers	TRI9 / ET9P
Total releases & transfers	TRI10 / ET10
Ores (metric tons)	
Safety	
Fatalities	FATL
Lost work days	LWD
Water use (billion gallons)	
Intake	WINT
Recycled/Reused	WREC
Discharged treated and untreated	WDT
Pollutants to water (metric tons)	
Total suspended sediment	TSS
Total phosphorus	TP
Total nitrogen	TN
Biological oxygen demand (BOD)	BOD

[a]Data sources: 1) Carnegie Mellon, EIO-LCA website: www.eiolca.net; 2) NOAA Typical Pollutant Concentration Matrix: http://SPOserver.nos.noaa.gov/projects/gomexico/tpc_matrix.html.

to surface waters from industries by four-digit Standard Industrial Classification (SIC) sector. (For an explanation of SIC see the US Census Bureau Web site.) Table 1 shows the complete list of environmental burdens evaluated, although not all data or results are reported here.

Several types of data shown in Table 1 require further explanation: RCRA Hazardous Waste, Toxic Releases Unweighted and Weighted, and External Costs.

Hazardous wastes (RCRA-regulated). The Resources Conservation and Recovery Act (RCRA) provides for the management of solid and hazardous wastes from all generators and handlers. Hazardous waste includes a wide variety of manufacturing byproducts and waste materials. Regulated material is defined by the US Environmental Protection Agency (EPA) as any chemical that poses a hazard to human health or the environment. However, many wastes are excluded from RCRA regulation to avoid duplication with other programs, such as radioactive materials.

Toxic releases from the Toxics Release Inventory. The substances included in US EPA's Toxics Release Inventory (TRI) include "toxic chemical releases and other waste management activities reported annually by certain covered industry groups and federal facilities" (US EPA 2001). The primary purpose of the inventory, according to the EPA, is to inform communities of local chemical hazards. The inventory focuses on the most toxic chemicals used or produced by industry, as opposed to RCRA that includes a broader range of potentially harmful materials.

We considered both the quantities of toxics released in terms of raw metric tons (referred to as *unweighted*) per job as well as toxics weighted by their relative toxicity (referred to as *weighted*) per job. The TRI toxics were weighted based on threshold limits of exposure levels developed by the American Conference of Governmental Industrial Hygienists (ACGIH) using the Carnegie Mellon University Equivalent Toxicity weighting scheme (Horvath and others 1995). Only those toxics with known exposure limits were included in the weighting scheme. It is important to note that the TRI data represent estimates of toxic discharges and not human exposure to these chemicals.

External costs. Translating economic benefits and environmental effects into the common units of dollars is the goal of many resource managers. For this reason, our analysis includes some environmental burden indicators that are based on dollar valuation studies as a test of their applicability. However, we do not use the monetary values explicitly due to these limitations.

External or externality costs are those costs that are imposed on society as a whole or on a particular group but not borne by the industry that creates them. Thus, these costs are external to the production process and cost accounting of an industry. Typically, externality costs are thought of as the health impacts or lost use of public areas that may occur because of pollution releases from a manufacturing plant. However, these costs can include a broad range of costs imposed through diminished quality of ecological systems that produce public goods and services (Austin and others 1998).

The external cost multipliers used here were developed to estimate costs imposed on society from the emission of an additional ton of individual conventional air pollutants (SO_2, CO, NO_2, VOC, PM_{10}) and gases contributing to global climate change: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and chlorofluorocarbons (CFCs) (Matthews and Lave 2000). The costs in the EIOLCA database are estimated based on a wide range of economic valuation studies that assessed costs due to, primarily, health impacts but also due to damages to crops and materials and amenity losses from an additional ton of an air pollutant in specific locations. Because the economic values vary greatly depending on specific local conditions (Matthews and Lave 2000, King and Mazotta 2001), the dollar values should be seen as indicators of potential relative costs between regions rather than taken literally.

TPC dataset. The TPC matrix data were developed primarily from studies of end-of-pipe discharge concentrations (Arnold and Farrow 1987). The values represent average actual concentrations for SIC industrial categories based largely on values reported in compliance with National Pollution Discharge Elimination System (NPDES) permit requirements, which covers waste treatment facilities and industrial dischargers. Due to overlap with the EIOLCA dataset, we selected only four of the wastewater-related output variables available in the TPC database: biological oxygen demand (BOD), total suspended solids (TSS), total nitrogen, and total phosphorus. Excess of any of these constituents is thought to impair water quality for a variety of uses and reduce habitat quality for certain organisms. The TPC database pollutant concentrations were converted to quantities per million dollars of output by multiplying the concentration values by the amount of water discharged per million dollars of production output, as provided by the EIOLCA database. Although the TPC data had independent values for water discharge by industry, there was insufficient information to relate those data to value of production, as required for this analysis.

Generating Total Environmental Burden Levels

To calculate each environmental burden shown in Table 1, we multiply the burden rate (burden per million dollars output) by the total economic output of each of the 528 economic sectors and sum over a subset of the economic sectors, depending on the

Table 2. Aggregated economic sectors used in analysis

Sector	Abbreviation used in tables
Agriculture, forestry, and fishing	FARM
Mining	MINE
Construction	CONS
Manufacturing	MANU
Transportation and public utilities	TRAN
Wholesale and retail trade	WHOL
Finance, insurance, real estate	FIN
Services (includes business, health, personal, education, social, and legal services)	SERV
State and local government	LGOV
Federal government	FGOV

industry being evaluated. For any county, the total environmental burden in terms of a particular pollutant emission or resource consumption (u_a) (e.g., tons of CO_2 emitted) equals:

$$u_a = \sum_{i=1}^{n} o_i p_{ia} \qquad (1)$$

where o_i represents the output (value of all shipments plus net additions to inventory in millions of dollars) for an economic sector i and p_{ia} represents the rate of environmental burden a per million dollars of output of economic sector i (e.g., CO_2 emitted per $million output in electric services). Thus, the pollution or resource use rates are linearly related to the output of individual sectors. Each calculated environmental burden has its own appropriate unit of measure (e.g., billion gallons of water used or metric tons of gases released). The calculations are made for each of the resource burdens and for each Maryland county.

The total burden due to economic sector i is represented as the sum of the individual burdens of n industries (out of 528 total) that make up the ith sector. We use the typical BEA classification system to group businesses into 10 aggregated sectors (Table 2). The final result of the calculations is a set of matrices, one for each county, with the 10 aggregated economic sectors (and the total for all industries) in the rows, and burdens in the columns.

Generating Rates of Burden per Economic Benefit

Once the basic burden quantities generated by industrial group and by county are calculated, we create the *rates* of environmental burden per economic benefit. To compare the amounts of environmental burdens generated per economic benefit within each of the 10 economic sectors by county, we divide the total environmental burden for each aggregated economic sector (e.g., fertilizer purchases for the Farming sector) by the total number of jobs (average number of full and part-time jobs, including self-employed individuals, as full-time job equivalents) in that sector to derive the burden per job for that sector within that county. The intent is to gauge, for any given industry, the estimated environmental burden that a county is accepting for the economic benefit of jobs, and to compare these values across counties.

Summary Statistics and Cluster Analysis

Many of the environmental burdens per benefit variables are highly correlated with each other. Therefore, we reduce the set of variables to examine by conducting two types of statistical analysis in sequence. First, we calculate summary statistics and correlation coefficients of the variables to assist us in identifying and selecting those burden per benefit variables providing the most useful information for distinguishing among counties. The selected set of variables is then grouped into six indicator categories based on similarity of resource use or type of emission [Air Pollution, Energy Use, Hazardous Substances listed in the Resource Conservation and Recovery Act (RCRA) and Toxics, Global Warming Gases, Water Use and Pollution, and External Costs and Safety]. In the second analysis, for each indicator category, we use cluster analysis to create groups of counties with distinct burden per benefit characteristics. This two-step analysis more readily reveals similarities, differences, and extreme values among counties.

To choose the burden per benefit variables that varied substantially from county to county, and were thus most interesting to examine, we used three criteria: range, skewness, and the difference between the maximum value and the upper 95% confidence limit. We focused on those burden per benefit variables that exceeded selected thresholds of at least one of these statistics. The thresholds used were based on obvious breaks in the data or on the proportion of variables selected. We also eliminated highly correlated burden per benefit indicators to simplify the analysis.

Cluster methods. To compare counties in terms of their scores on more than one burden per benefit indicator simultaneously, we use cluster analysis, one of several multivariate statistical techniques commonly used to evaluate similarities and differences between sampling units when multiple, potentially correlated variables are measured. Using cluster analysis, we are able to group together counties that score similarly on *sets* of burden per benefit indicators to show which counties are alike or different and which indicators best serve to differentiate the counties. We conduct separate cluster analyses for each of five resource areas: Air Pollution, Energy Use, Global Warming Potential (GWP), Water Use & Pollution, and RCRA & Toxics. Energy Use and GWP results are omitted from this paper due to space limitations.

Using the selected sets of variables, we use the scaled k-means clustering algorithm available within the Web-based LOICZ software (www.palantir.swarthmore.edu/loicz, Maxwell and Buddenmeier 2002) to develop the clusters. This method is one of a set of clustering methods that uses a similarity or distance matrix to assign samples to distinct clusters. To calculate similarity between counties, each county is plotted within a multidimensional state space where each axis is represented by a different burden per job indicator. A county's scores on a group of indicators (the vector of scores) will plot as a single point in this state space. Once all the counties are plotted in the state space, the differences between counties can be represented by the Euclidian distances between the data points.

Clusters are developed such that counties that plot near each other in state space (i.e., have similar scores for sets of burden per job indicators) are grouped together and distances between clusters are maximized. Each cluster is described based on the indicators that tend to most separate that cluster from other clusters. Distinguishing variables generally have average cluster scores that are particularly high or low (relative to the total range for all counties being compared) and have low variability among the counties within the cluster. By using this technique, variables that have different units or vary widely in magnitude can be readily compared because different indicator scores are made comparable by scaling the scores based on the variance among scores for particular counties.

Because cluster boundaries can vary in their distinctiveness based on how cleanly the data break in various dimensions, the degree of difference between clusters is represented using a relative (unitless) distance measure. The distance is measured between the calculated points that represent average values for each cluster. The higher this distance is between clusters, the more well defined the clusters. This distance cannot be tested for significance and can only be used in comparison to other distances among clusters.

Results of the Maryland Case Study

The evaluation of probable environmental burdens per job revealed some surprising distinctions among Maryland's 23 counties and 1 city that is a county-equivalent (hereafter referred to as 24 counties) as well as many similarities across the state. It is important to remember that the burden values we report for counties are based on national average outputs by industries present in the counties, and although the values account for actual economic output within the county, they are not based on pollution emission or resource use data specific to the businesses there. Therefore, *the indicators presented are probable environmental burdens for an economic sector* divided by the best available measurement of full-time job equivalents for that sector in that county.

The following sections highlight some of the more interesting results of the analyses for the resource categories of Air Pollution, Water Use & Pollution, Hazardous and Toxic Wastes, and External Costs. Cluster results were not conducted for external costs, so results cover the summary statistics only. The description of the first category of results, air pollutants, contains more detail than subsequent sections to orient the reader to differences in the indicators generated here versus the more typical indicators showing total pollutants generated.

Conventional Pollutants to Air

Conventional pollutant emissions to air are primarily of interest because they can negatively affect human health. Total emissions of conventional pollutants are generally low for the state of Maryland as a whole; it ranks below the median of all states (29th to 42nd) for most conventional pollutant emissions, although it ranks 19th for SO_2 emissions (US EPA 2000). However, several counties have large emissions from one or more economic sectors. The Construction sector appears to be the major emitter of particulate matter less than 10 microns (PM_{10}) in all Maryland counties, and Mining is likely to contribute significant amounts in others despite its relatively low level of economic output. However, Manufacturing or Transportation & Utilities were the primary emitters of total conventional air pollutants in Maryland, although Construction emits more carbon monoxide (CO) and nitrogen dioxide (NO_2) in some counties.

Unlike an analysis of total emissions, the focus of the burden per benefit indicators is to compare the amount of pollution generated per job either for the county's economy as a whole or for particular economic sectors. For any given air pollutant generated

Table 3. Estimated PM_{10} emissions and PM_{10} per job in manufacturing for Maryland counties

County	Total PM_{10} emissions from manufacturing (metric tons)	Manufacturing employment (Full-Time Equivalents)	PM_{10} emissions per job in manufacturing (tons/FTE)
Allegany	209.09	4586	0.046
Anne Arundel	22.07	15628	0.001
Baltimore	1403.19	36845	0.038
Baltimore City	410.83	33143	0.012
Calvert	4.55	746	0.006
Caroline	3.37	1522	0.002
Carroll	594.28	6363	0.093
Cecil	17.43	3683	0.005
Charles	6.67	1384	0.005
Dorchester	6.82	3770	0.002
Frederick	294.77	7239	0.041
Garrett	42.01	1587	0.026
Harford	26.10	4660	0.006
Howard	28.45	6925	0.004
Kent	2.40	942	0.003
Montgomery	40.56	20,626	0.002
Prince Georges	25.27	11,410	0.002
Queen Annes	7.57	1031	0.007
Somerset	0.19	495	0.000
St Marys	6.37	636	0.010
Talbot	5.66	3204	0.002
Washington	275.71	8551	0.032
Wicomico	31.85	7442	0.004
Worcester	13.24	2463	0.005

within a county and within an economic sector, the *total* emissions can be examined to understand, say, potential health impacts. For our indicators, we divide total emissions by the total jobs in that sector to get the *rate* of pollution generated per job in order to provide insight into how the burdens created by an economy compare to the benefits, relative to other counties or regions.

From our analysis of conventional air pollutants, we find that the highest rates of emissions per job for a given economic sector are generally not from the county whose economic sector had either the highest or the lowest emissions of total pollution. Therefore, the ratios of pollution per job give us different information to help us understand how economic structure and type of industry vary across the region. For example, although Baltimore County has the highest total emissions of PM_{10} within the Manufacturing sector, when the large number of jobs in that sector is considered, its rate of PM_{10} emissions per job is half that of the highest emitter per job, Carroll County (Table 3 and Figure 2). Carroll County has the second-highest levels of total PM_{10} emissions (although well below Baltimore County) and total employment in the Manufacturing sector that is about average for the state, leading to a high burden per benefit in this category. This high burden per benefit rate in Carroll County indicates that fewer jobs are generated for every ton of PM_{10} emitted by the Manufacturing sector compared to other Maryland counties. Thus, a relatively high rate of emission per output can occur independently of total pollution emissions or total economic activity.

Cluster Results for Conventional Air Pollutants

The burden per benefit indicators calculated for air pollution (Table 1) were reduced to a set of 12 indicators using the statistical screening methods, before the cluster analysis was performed (Figure 3 and Table 4). The cluster analysis shows that the variables that most distinguish the clusters (and the counties they contained) are SO_2 emissions per job for the Construction, Manufacturing, and Transportation & Utilities sectors and for all sectors combined. PM_{10} emissions per job in Mining helped to distinguish some counties that otherwise shared overall low emission rates of SO_2 with other counties.

The most important differences we find within the cluster results are that four counties (Allegany, Frederick, Carroll, and Baltimore Counties) in Cluster 1 have distinctly high rates of SO_2 emissions per job and that Calvert County (Cluster 3) is an outlier because of very high SO_2 emissions within the Transportation &

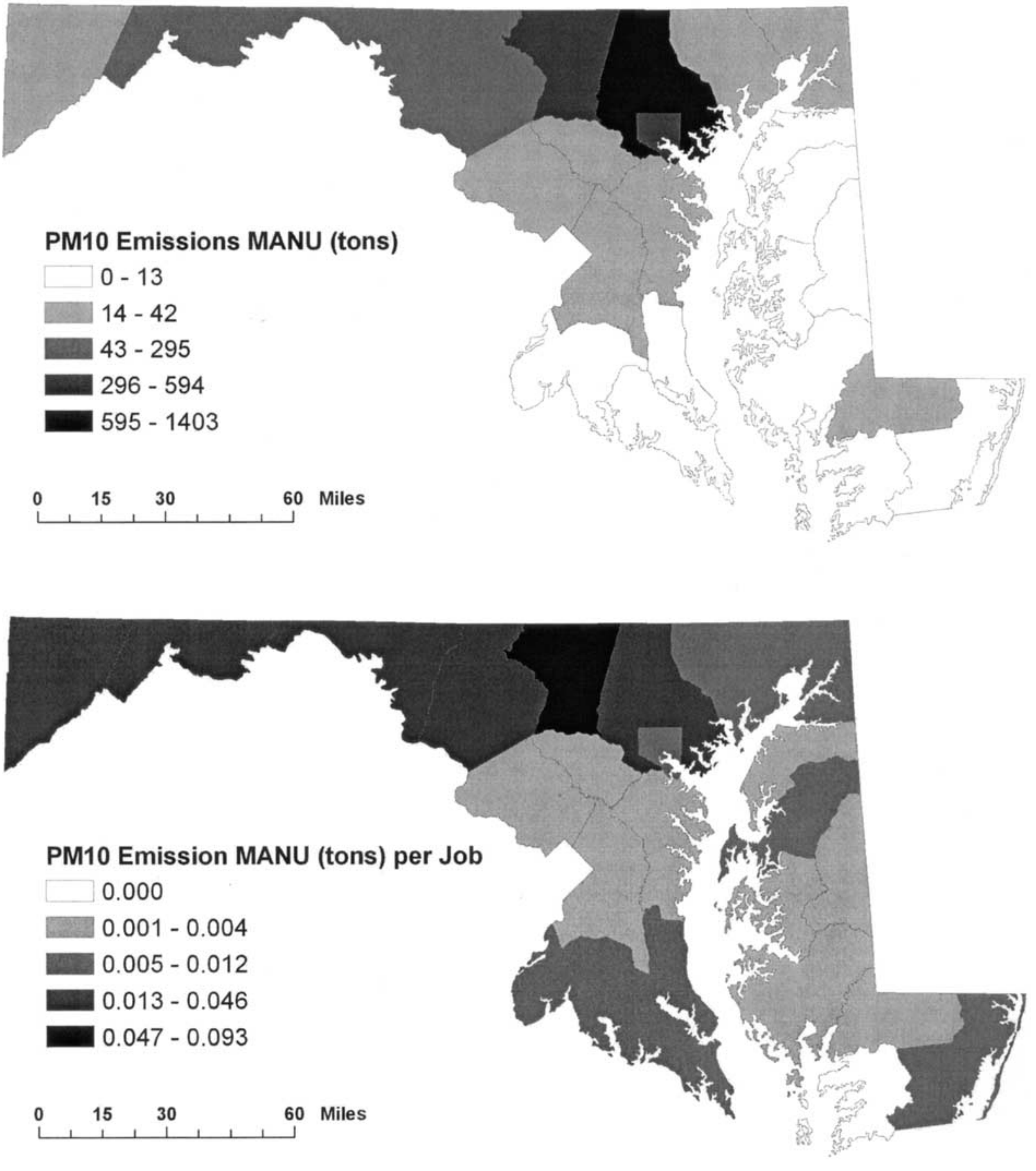

Figure 2. Comparison of environmental metrics using PM_{10} emissions from Manufacturing (MANU). Upper figure shows a typical metric for total pollution loading, total particulate matter less than 10 microns (PM_{10}), whereas the lower figure shows our indicators of the ratio of the PM_{10} emissions to the number of jobs in the Manufacturing sector. A substantial variation in the ratio of emissions per job among counties is evident and does not follow the pattern of total emissions. This difference in pattern shows that some counties are accepting higher air pollution burdens for the benefit of jobs than others, and the ratios are not merely reflections of total emissions or total employment. (See also Table 3). Similar distinctions between total burdens and burden per job could be drawn for many of the variables evaluated.

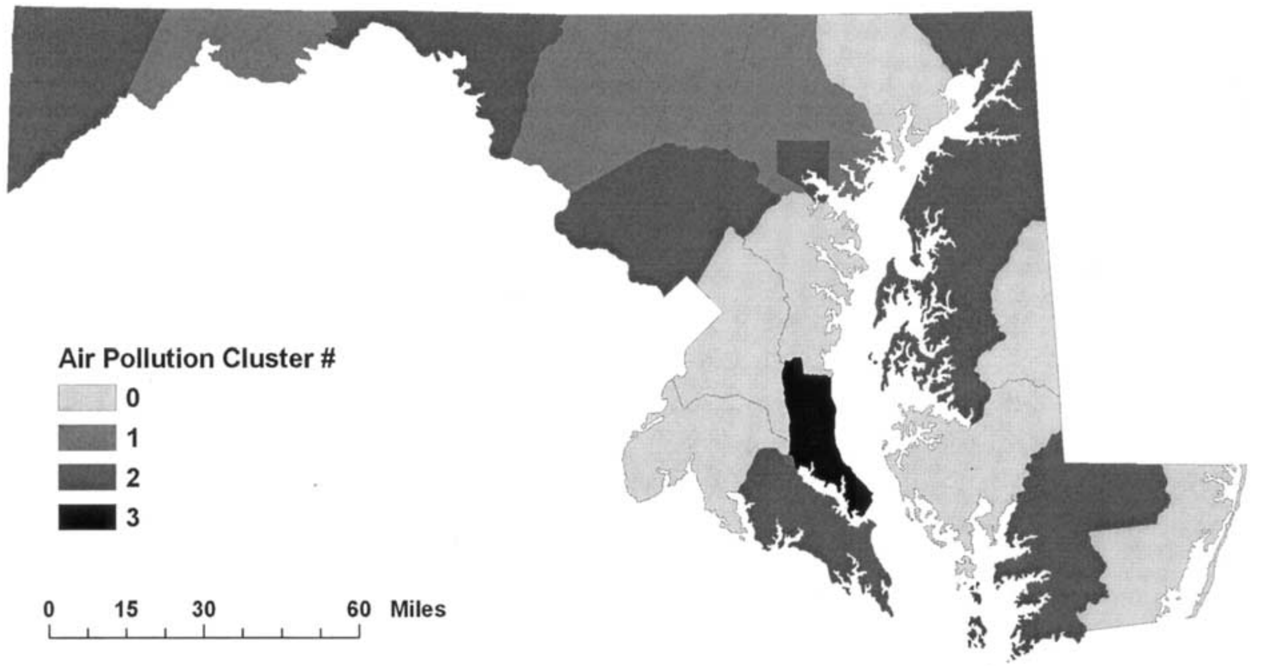

Figure 3. Air Pollution Cluster results. Variables important in defining clusters have high, medium, or low in the column representing the cluster (Table 4) to show whether the variable is in the top, middle, or bottom third of the variable range. PM_{10} for the Mining sector was important for distinguishing the clusters that contained the majority of counties (clusters 0 and 2). The air pollution values for Cluster 3 (Calvert County) are overestimates because the Transportation & Utilities sector in the county is dominated by a single nuclear power plant, whereas pollution values are calculated for the Electricity producing sector as a whole. Refer to Table 2 for economic sector definitions.

Table 4. Air Pollution Cluster results

Cluster number	0	1	2	3
No. counties (% of total)	7 (29%)	4 (17%)	12 (50%)	1 (4%)
SO_2 CONS	Low		Low	
SO_2 MANU	Low	High	Low	
SO_2 TRAN		Low		High
SO_2 LGOV				
SO_2 All sectors	Low		Low	High
CO MINE				
CO MANU				
CO TRAN				
NO_2 MANU				
NO_2 TRAN				
VOC CONS				
PM_{10} MINE	High		Low	

Utilities sector. For Calvert County, whose Transportation & Utilities sector is dominated by a single nuclear power plant, the calculated pollution per job is particularly misleading. (See Discussion and Conclusions section for further attention to this topic.) Half of the counties fall into a cluster marked by low SO_2 emissions per job (Cluster 2). The bulk of the remaining counties fall into Cluster 0, which is only differentiated from Cluster 2 by high PM_{10} emissions per job in Mining. Clusters 0 and 2 are not highly distinct because their characteristics map close together in state space.

Water Use and Water Pollutants

The indicators of water use and pollution discharges per job clearly identify the counties that are likely to be the top water users and point source dischargers per job in the Manufacturing sector. Allegany and Baltimore Counties show consistently high rates of water use per job in Manufacturing relative to other counties. Furthermore, Allegany (Cluster 1), Baltimore (Cluster 2), and Charles (Cluster 0) Counties each form distinct clusters made up solely of that single county based primarily on high outlier values in a single water quality indicator: Biological Oxygen Demand (BOD) per job, Total Nitrogen (TN) per job, and Total Phosphorus (TP) per job, respectively (Figure 4, Table 5).

Results for the water use and pollution indicators show that the highest burden rates per job do not necessarily coincide with the overall level of activity within an industry, but rather reflect differences in the type of manufacturing being conducted. Baltimore

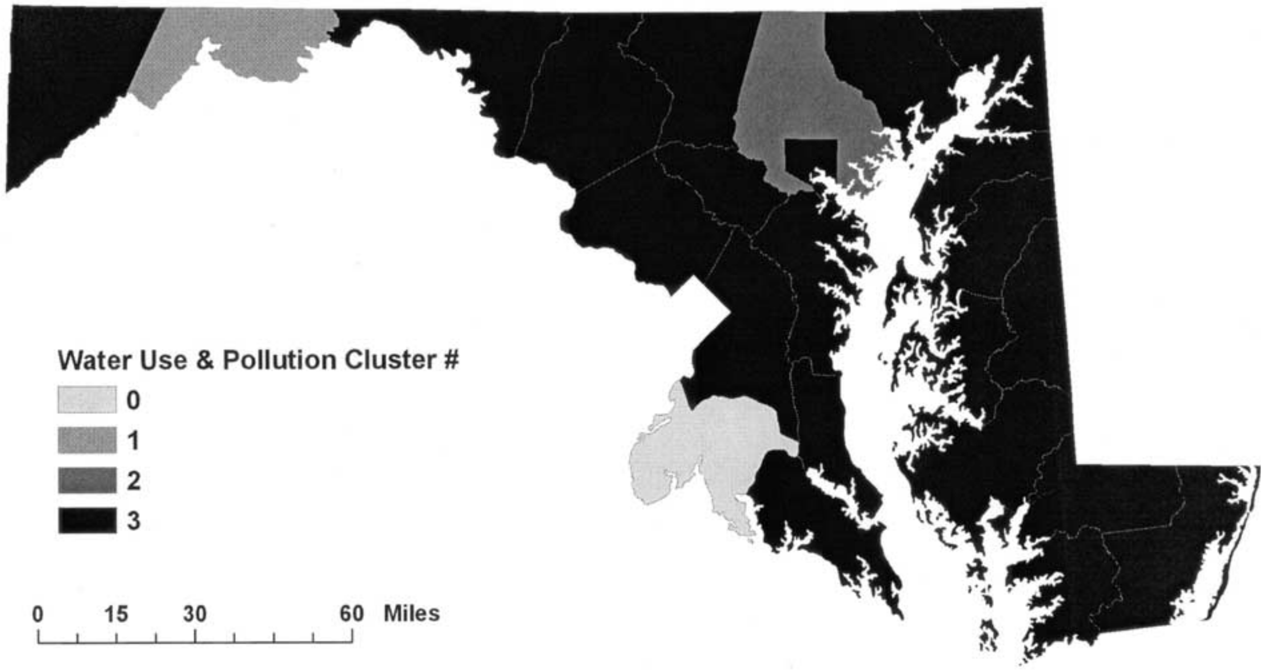

Figure 4. Water Use and Pollution Cluster results. Variables important in defining clusters have high, medium, or low in the column representing the cluster (Table 5). Three counties showed extreme values in one or more variables, thus creating three clusters of a single county each. Baltimore City, despite having rather high biological oxygen demand, total suspended sediment, and total nitrogen discharges per job, was consistently assigned to the low-pollution-discharge cluster. This demonstrates how the differences between clusters are scaled according to the extremes of the data. Using more clusters would have separated Baltimore City from the low-discharge counties, but for this number of clusters Baltimore City is more similar to the lowest dischargers than to the top dischargers. Refer to Tables 1 and 2 for definitions of abbreviations.

Table 5. Water Use and Pollution Cluster results

Cluster number	0	1	2	3
No. counties (% of total)	1 (4%)	1 (4%)	1 (4%)	21 (88%)
Water recycled MANU	Low	High	Medium	Low
Water discharged treated MANU				
Biological oxygen demand MANU		High	Low	
Total suspended solids MANU				
Total nitrogen MANU			High	Low
Total phosphorus MANU	High			Low

City and Baltimore County both have high employment in the Manufacturing sector, but the levels of water use and pollution discharge rates per job are quite different. Baltimore County shows much higher levels of water use and TN emissions per job compared to Baltimore City, but the city shows elevated emissions of BOD per job relative to Baltimore County. Conversely, Allegany County, which has below average levels of employment in Manufacturing, has some of the highest water use and pollution discharge rates per job.

Hazardous and Toxic Wastes

We lump together all variables for hazardous and toxic wastes, including toxics as raw totals and as toxic equivalents for purposes of the cluster analysis. The Manufacturing and Transportation & Utilities sectors tend to be the major producers of both toxics and RCRA waste per job, suggesting that separate analyses for these two wastes would yield similar results. Furthermore, toxic variables, when unweighted by toxicity, generally did not show much variability between counties.

Cluster Analysis for RCRA, Toxics, and Weighted Toxics

By removing correlated variables among the RCRA and Toxics variables, we reduced the set of indicators used in the cluster analysis to nine (Figure 5, Table 6). The variables that distinguish clusters are Toxic Offsite

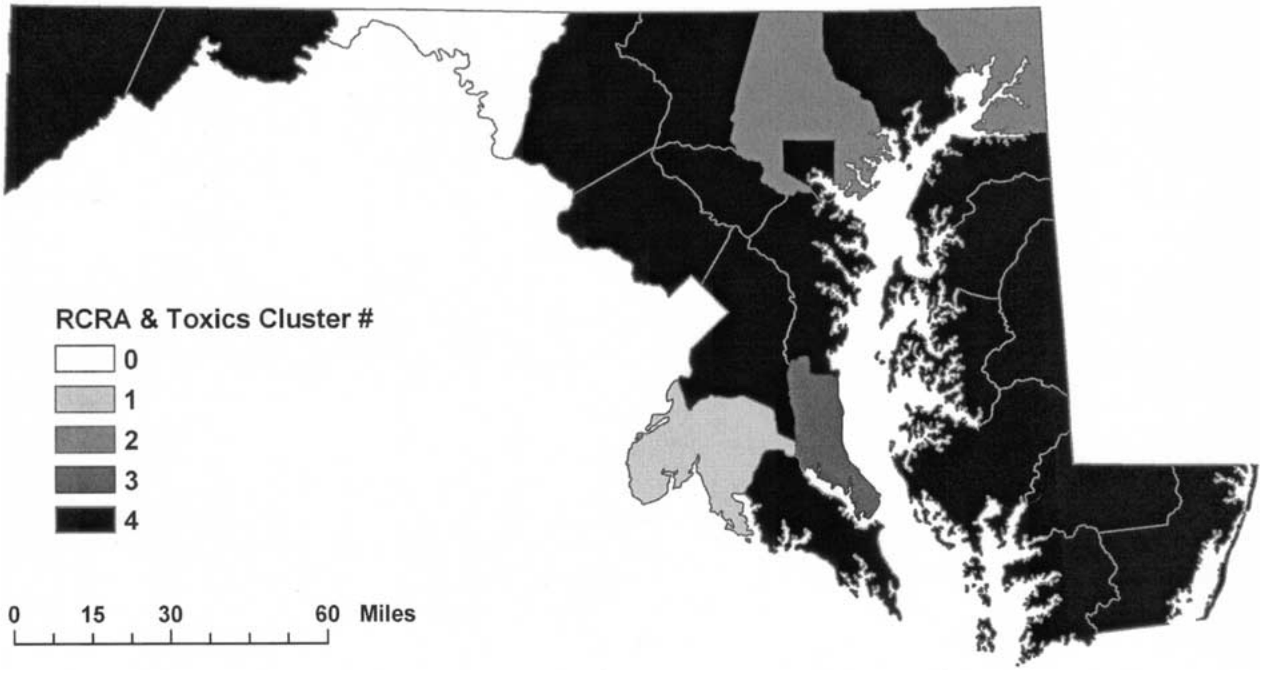

Figure 5. Resources Conservation and Recovery Act (RCRA) and Toxics Cluster results. Variables important in defining clusters have high, medium, or low in the column representing the cluster (Table 6). Offsite Transfers of toxics (unweighted) and Toxic Releases (weighted by toxicity) from Publicly Owned Treatment Works (POTW), both from the Manufacturing sector, were important variables for distinguishing the two largest clusters. Refer to Tables 1 and 2 for definitions of abbreviations.

Table 6. RCRA and Toxics Cluster results

Cluster number	0	1	2	3	4
No. counties (% of total)	1 (4%)	1 (4%)	2 (8%)	1 (4%)	19 (79%)
Toxic offsite transfers MANU			High		Low
Toxics (weighted) POTW MANU	High		Low	Low	Low
Toxics (weighted) offsite transfers MANU					
Toxics (weighted) total releases & transfers MANU					
Toxics (weighted) total releases & transfers TRAN			Low	High	Low
RCRA generated MANU					
RCRA generated TRAN		High			
RCRA shipped MANU					
RCRA shipped TRAN	Low	High		Low	

Transfers (unweighted) per job in Manufacturing, which distinguishes the cluster containing Cecil and Baltimore Counties (Cluster 2), weighted Toxic Releases from POTWs in Manufacturing (Washington County, Cluster 0); RCRA wastes Generated and Shipped per job in Transportation & Utilities (Charles County, Cluster 1) and Total Releases & Transfers per job in Transportation & Utilities (Calvert County, Cluster 3).

It is clear from examining the indicators that characterize clusters, that despite having combined all the hazardous and toxic variables, the cluster analysis is able to draw distinctions among Maryland counties in terms of different types of wastes emitted per job. The

Table 7. External costs (based on medium estimates) in millions of dollars per 1000 jobs

County	Farming	Mining	Construction	Manufacture	Transport & utilities	Wholesale & retail trade	Services	All sectors
Allegany	0.134	28.119	1.030	3.817	6.422	0.043	0.044	0.970
Anne Arundel	0.150	25.346	1.106	0.272	6.920	0.107	0.078	0.468
Baltimore	0.205	14.209	1.143	4.257	7.266	0.107	0.073	0.764
Baltimore City	0.118	20.016	1.142	0.780	8.591	0.165	0.072	0.535
Calvert	0.344	17.207	1.077	0.347	48.481	0.029	0.058	3.884
Caroline	1.074	23.160	1.030	0.394	7.715	0.051	0.109	1.107
Carroll	0.494	26.444	1.026	2.906	5.620	0.093	0.059	0.668
Cecil	0.572	12.604	1.032	0.519	5.623	0.065	0.059	0.540
Charles	0.319	30.240	1.075	0.602	9.306	0.050	0.052	0.600
Dorchester	1.045	14.928	1.002	0.200	5.701	0.082	0.064	0.506
Frederick	0.283	21.493	1.042	2.414	7.106	0.095	0.065	0.551
Garrett	0.197	35.169	1.496	0.745	5.810	0.052	0.043	0.976
Harford	0.297	32.794	1.037	0.563	5.906	0.075	0.062	0.353
Howard	0.200	8.917	1.188	0.312	4.352	0.178	0.075	0.421
Kent	0.526	2.744	1.054	0.287	11.095	0.072	0.070	0.599
Montgomery	0.162	6.641	1.198	0.258	2.052	0.120	0.077	0.193
Prince Georges	0.161	20.504	1.120	0.320	7.485	0.107	0.082	0.550
Queen Annes	0.675	0.000	0.986	0.320	5.450	0.073	0.080	0.391
Somerset	0.746	34.707	0.917	0.307	9.470	0.167	0.047	1.257
St Marys	0.470	5.339	0.977	0.284	3.252	0.046	0.049	0.296
Talbot	0.695	1.900	1.072	0.265	3.593	0.082	0.051	0.278
Washington	0.380	5.553	1.014	1.321	7.810	0.086	0.119	0.676
Wicomico	0.965	6.451	0.987	0.308	8.048	0.101	0.059	0.580
Worcester	1.078	23.616	0.957	0.224	9.010	0.050	0.054	0.367

cluster results appear particularly robust for this group of indicators because the distances between clusters are uniformly high.

External Costs or Cost-Weighted Air Emissions

Because of the way the external cost dollar values are calculated here (see data sources), we view the calculated costs as a weighted index of environmental burdens from air pollution emissions rather than as monetary damage estimates. The dollar values attached to certain air emissions can be thought of as weights on those air pollutants in terms of the costs they could potentially impose if certain conditions are met. Because the dollar values are primarily based on health costs, these values might best be applied in areas known to exceed EPA clean air standards, where the assumption that increases in pollution will tend to increase health costs would be most reasonable. In Maryland, nine counties are nonattainment areas for ozone standards, but air quality meets or exceeds standards for the other conventional air pollutants evaluated here (US EPA 2003b).

Summary Statistics for Externality Costs

The external costs (using medium values) per 1000 jobs are generally low for all Maryland counties, but are highest in the Mining and Transportation & Utilities sectors (Table 7). Within the Mining sector, the highest cost calculated for a single county is $35 million per 1000 jobs and within Transportation and Utilities is $48 million per 1000 jobs.

Using our summary statistics criteria results in only one variable being selected for comparing counties: external costs for Transportation & Utilities and for all sectors combined. This indicator was chosen based on its skewness, and thus its selection was strongly influenced by the outlier value for Calvert County in the Transportation & Utilities sector. Because the values for the Transportation & Utilities sector in Calvert County are suspect, the external cost indicators per job do not appear to be particularly valuable in distinguishing counties. These values may better serve to demonstrate the potential impacts of total industry activity rather than serve as part of our burden per benefit indicators.

Discussion and Conclusions

The results of our cluster analyses on the burden per benefit indicators demonstrate that these indicators can be used to show aspects of resource use that are often independent of patterns of total resource use and are complementary to measures of total resource use. The indicators illustrate tradeoffs between resource use and economic benefits and therefore, can inform decisions about how to manage scarce resources while avoiding impacts to economies of a region. For example, the indicators suggest that any sweeping water use restrictions would be felt the most severely by manufacturing businesses in Allegany and Baltimore counties, which have the highest water use rates per job and the highest total water use (data not shown). If we assume the businesses are using water efficiently, then restrictions on water use are more likely to result in lost jobs than in an industry with lower water use per job. On the other hand, the high resource use per job may also represent an opportunity to examine reducing resource use through enhanced efficiency. An understanding of the dependence of a job on resource use levels allows the potential impact of management solutions to be assessed and weighed against the benefits of implementing such a management action.

Comparing the burden per benefit indicators across regions may provide a measure of the flexibility a region has to adjust to changes in resource conditions, such as increasing scarcity in certain inputs to production. Clearly, the many companies that generate a region's economic output and jobs will have various abilities to adapt to changes in resource pressures, so we do not have a true measure of the elasticity of demand for natural goods or services. However, these indicators can be used to compare efficiencies across areas and across industries to pinpoint where heterogeneous conditions exist that may, for example, favor trading of pollution credits. Assessing the heterogeneities of a region could be a useful step in assessing which regions have the capacity to implement management options in response to changing resource conditions.

The burden per benefit indicators are meant to be used in combination with indicators of resource condition and with measures of total environmental burdens in order to contribute to analyses of regional economic risk from changes in natural resource condition. Data on where pollution exceeds allowable levels or where aquifer levels are dropping to undesirable levels will demonstrate where ecosystem services are currently being strained. Other information can serve to indicate where new risks may emerge. When our indicators are combined with such information about resource condition, they can reveal contributors of stress and potential avenues for management that take into account impacts on local economies.

The indicators are not without their problems. As expected, certain conditions will limit their accuracy and usefulness at the scale of a county. The problems are typical of data problems associated with aggregating or disaggregating data for regional analysis and stem from the fact that the production functions, which represent industry averages within each of the 528 sectors, do not hold if a county's sector is dominated by one or a few atypical businesses. Although further industrial disaggregation would prevent some of these problems, the data clearly become unwieldy if we cannot group businesses into categories. While not perfect, the information derived from economic production functions is often the best available for assessing resource use consistently over a region and offers a means to evaluate tradeoffs between resource use and economic benefits using comparable datasets. The following discusses the quality of the indicators in more depth.

The Indicators Are Responsive to Underlying Economic Structure

Some counties show consistently high or low environmental burden per benefit rates across indicator categories, reflecting dominant characteristics of the economic structure. From the cluster analyses, we see that in every environmental category evaluated, either one of or usually both Baltimore and Allegany counties have high estimated burden rates per job for the variables that distinguished clusters. Other counties have consistently low burdens per job across indicators, such as Montgomery County. On the other hand, counties that demonstrate low burden rates for most indicators often have modest to high rates for a select set of indicators, suggesting that locales may have concentrations of particular burdens likely due to spatial clustering of similar industries (Bergman and Feser 1999).

The spatial clustering of industry may be the reason that some relatively rural counties are estimated to have some of the highest ratios of burdens per job for specific pollutants. Rural Cecil County has extremely high RCRA waste generation rates per Manufacturing job and Harford shows high PM_{10} emissions per job from Mining. These high values contrast with the typically low values for other air pollution and toxic indicators seen in these counties. An economic sector in a rural county is more likely to be dominated by a few businesses, so clusters of industry that tend to create a particularly high burden per job will be more apparent than in counties with larger economies.

Size of the Economy Is Important in Some Cases, but Results Are Typically Independent of Total Sector Employment

We find some relationship between total size of the economy and the tendency of a county to have relatively high or low burden per benefit indicator values, but this does not explain all, or even most, county rankings. All sizes of economic sectors (in terms of either total output or total employment) demonstrate the ability to fall at either the top or the bottom of the rankings. When we compare Baltimore County and Baltimore City, we find that despite comparably sized Manufacturing sectors, Baltimore County's pollution emissions per job in this sector are among the highest of all Maryland counties, while Baltimore City often ranks well below Baltimore County for the same burden per job indicators.

When burden rates are independent of total economic output or jobs, they demonstrate that some counties receive relatively more economic benefits per level of environmental burden because of the nature of the specific businesses represented in the economic sector and not because of the overall size of the sector. These differences between county economies are the main differences we are attempting to quantify because they allow counties to examine how environmental burdens are being traded for jobs and economic activity, and what range of possible burden per benefit ratios exists. Such information may be most useful when making decisions about which types of industries should be encouraged to locate in an area if natural resources are showing signs of stress.

Production Function Assumptions Presented Challenges at Fine Geographic Scales

Calvert County appeared to be getting a bad deal with its Transportation & Utilities sector, which was estimated to generate unusually high burdens per job, until we delved deeper into the numbers. From examining our detailed economic data, which include data for 528 distinct economic sectors, it is clear that the Transportation & Utilities sector in Calvert County is dominated by the Electric Services subsector which, in turn, is dominated by a single power-generating plant. Therefore, the pollution per job generated for the Transportation & Utilities sector, is largely based on the average emissions of all electricity generators nationwide, and not on the specific power plant in Calvert, which happens to be a nuclear plant. Because nuclear plants generate only 20% of electricity nationwide (Nuclear Regulatory Commission 2001), the lack of direct emissions of conventional air pollutants from such a plant is not accurately reflected in the rates of pollution per job calculated here. In addition, the toxic emission estimates are also largely inaccurate because they do not include the radioactive wastes being generated and instead reflect wastes prevalent in conventional electricity-generating plants.

These results for Calvert's Transportation & Utilities sector highlight the difficulty of using national average numbers on a per-county basis. Although the methods we have developed here use the best available data, they are bound to produce inaccuracies at the scale of a county, particularly when a sector is dominated by one or a few industries whose characteristics are far from average. The use of 528 economic sectors is meant to minimize the problem of using average conditions across an industrial sector, but clearly cannot prevent all error related to using average industry conditions. The unusually high values calculated for indicators in this sector spurred us to delve deeper into the situation in Calvert County, allowing us to interpret these numbers more appropriately in our final summary. Nevertheless, we conclude that the indicator values are best used for regional screening and should be confirmed by additional analyses before serving as the basis of any management action.

How Much of a Difference in Indicator Scores Is Significant?

The cluster analysis methods, although less intuitive than examining indicators individually, are useful for their ability to simultaneously compare multiple indicators results among counties and for their ability to identify a small set of indicators that serve to differentiate the counties. Each set of cluster results helps us to judge which indicators may be most useful for comparing conditions of environmental burdens per economic benefit among regions. The analysis tests which indicators vary substantially between regions even though the actual magnitude of measured differences can vary widely. But are these differences significant?

Our methods allow only relative comparison between regions, which raises the issue of determining how much of a difference in indicator scores between counties is important. We attempted to highlight meaningful differences by using our two-stage approach to indicator selection. First, we omitted variables that showed little variability across regions, to avoid the possibility that the differences between counties were negligible. Second, the type of cluster analysis we chose is designed to draw out useful differences among samples by grouping counties in terms of deviations from the mean across multiple variables.

With the cluster techniques, we can examine which counties have distinctively higher rates of burden per benefit ratios based on the variability of the indicators across the region, much as one would do in a statistical test of significant difference. However, the method does not provide true significance testing. Once similar counties are grouped into clusters, we can compare how different the clusters are from each other using the (relative) cluster distance measures. Also, the cluster technique identifies the variables most useful for differentiating counties, and the magnitude of these variables can be examined in detail for relevance.

Typically, there is no one answer to ''how much'' of a difference is important, but the variable scaling method used within the cluster analysis to generate clusters provides an efficient way to examine potentially meaningful differences between counties and compare multiple indicators simultaneously.

Potential Application Over Broad Regions

This case study for one state was used to develop our methods and refine our techniques to examine economic vulnerabilities at a regional scale. As part of future analyses, we will examine situations where economic dependencies are juxtaposed with problematic resource conditions over the mid-Atlantic region. The output of these methods may be combined with other spatial data to consider the likely impacts of a range of economic activities on resources at particular locations and risk factors related to specific resources at other locations.

The indicators generated here may not be adequate to establish vulnerabilities to resource disruptions by themselves, but they serve as the first step in comparing economic activities with other conditions. They meet two criteria for useful indicators in that they can serve to help diagnose the cause of a resource problem or foresee problems due to economic growth that can be averted by forward-thinking managers (Dale and Beyeler 2001). Because economic structure is not fixed and average conditions may not hold for a given area, the results will need to be used cautiously when examining risk.

One drawback of available databases for creating indicators is that the data available to characterize pollution emissions and resource use per million dollars of economic output or per job are primarily focused on heavy industry. If the Service sector and other similar sectors continue to grow in the mid-Atlantic region and become a greater proportion of economic output and total employment, as is projected (US Department of Labor, Bureau of Labor Statistics), new databases will be needed to characterize the resource consumption and total pollution emissions of these sectors. Although the waste stream from ''white-collar'' industries may appear small on a per job basis, the increasing size of these sectors means that wastes and resource demands can develop into new and emerging problems for the future. The potential usefulness of understanding how resource needs change as sectors grow suggests that improving information would pay off in terms of improving resource risk management.

In summary, the indicators produced here are able to condense a great deal of information about the relationship between economies and environmental burdens, even though they clearly have their limitations when used at the county scale. They appeared to be sufficiently accurate for coarse regional analysis to examine tradeoffs between economic benefits and burdens to natural resources and ecosystem services. The use of the indicators successfully identified patterns that were distinct from aggregate size of economies and total environmental burdens of a region. Therefore, the indicators offer a distinct method for relating natural resource conditions to potential economic vulnerabilities and may be useful for assisting counties in planning economic growth that is consistent with environmental concerns.

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Literature Cited

Arnold, F. D., and R. G. Farrow. 1987. The National Coastal Pollutant Discharge Inventory: Pollution discharge concentrations for industrial point sources. Strategic Assessment Branch. Ocean Assessments Division. OOMA. National Ocean Service. National Oceanic and Atmospheric Administration. Report.

Austin, D.H., A.J. Krupnick, D. Burtraw, and T. Stoessell. 1998. The benefits of air pollutant emissions reductions in Maryland: Results from the Maryland Externalities Screening and Valuation Model. Resources for the Future Discussion Paper #99–05.

Bergman E. M., and E. J. Feser. 1999. Industrial and regional clusters: Concepts and comparative applications. The Web book of regional science. Regional Research Institute. West Virginia University. http://www.rri.wvu.edu/regscweb.htm.

Bockstael, N. E., A. M. Freeman III, R. J. Kopp, P. R. Portney, and V. K. Smith. 2000. On measuring economic values for nature. *Environmental Science and Technology* 34:1384–1389.

Burks-Copes, K. A., A. C. Webb, A. A. Lee, and M. F. Passmore. 2002. Ecosystem restoration habitat assessment for the proposed East St. Louis and vicinity, Illinois (Ecosystem Restoration and Flood Damage Reduction Project). Draft report. U. S. Army Engineer Research and Development Center, Environmental Laboratory, Vicksburg, MS.

Carnegie Mellon University (CMU). 2000. EIOLCA Website. http://www.eiolca.net.

Dale, V. H., and S. C. Beyeler. 2001. Challenges in the development and use of ecological indicators. *Ecological Indicators* 1:3–10.

Diamond, P. A., and J. A. Hausman. 1994. Contingent valuation: Is some number better than no number? *The Journal of Economic Perspectives* 8:45–64.

Dockery, D. W., C. A. Pope III, X. Xu, J. D. Spengler, J. H. Ware, M. E. Fay, B. G. Ferris Jr., and F. E. Speizer. 1993. An association between air pollution and mortality in six U.S. cities. *New England Journal of Medicine* 329:1753–1759.

Horvath, A., C. T. Hendrickson, L. B. Lave, F. C. McMichael, and T.-S. Wu. 1995. Toxic emissions indices for green design and inventory. *Environmental Science and Technology* 29:86–90.

King, D. M., and M. Mazotta. 2001. Ecosystem valuation Web site. http://www.ecosystemvaluation.org. Authors affiliated with University of Maryland and University of Rhode Island. Site sponsored by the USDA NRCS and NOAA. Last accessed July 2002.

Leontief, W. W. 1986. Input–output economics, 2nd ed. Oxford University Press, New York.

Matthews, H. S., and L. B. Lave. 2000. Applications of environmental valuation for determining externality costs. *Environmental Science and Technology* 34:1390–1395.

Maxwell, B.A., and R. W. Buddemeier. 2002. Coastal typology development with heterogeneous data sets, regional environmental change 3(1–3): 77–87; also Kansas geological survey open-file report 2000-53.

Minnesota IMPLAN Group (MIG). 1999. IMPLAN Professional™ version 2.0. First edition, April 1999. Stillwater, Minnesota.

Noss, R. F 1990. Indicators for monitoring biodiversity: A hierarchical approach. *Conservation Biology* 4:355–364.

Nuclear Regulatory Commission. 2001. Statement submitted by the United States Nuclear Regulatory Commission to the Subcommittee on Energy and Air Quality Committee on Energy and Commerce United States House of Representatives for the Hearing on Hydroelectric Relicensing and Nuclear Energy. Submitted by Richard A. Meserve, June 27, 2001.

Pacheco, P. A., A. S. Pait, S. J. Arenstam, A. E. DeSouza, D. R. G. Farrow, J. J. Hayes, M. J. Katz, J. Lowe, and M. Swain. 1993. Point source methods document. Pollution Sources Characterization Branch, Strategic Environmental Assessments Division, Office of Ocean Resources Conservation and Assessment, National Ocean Service, National Oceanic and Atmospheric Administration (NOAA), Silver Spring, MD. See also: http://SPOserver.nos.noaa.gov/projects/gomexico/ps_inventory.html.

Ribaudo, M. O., D. L. Hoag, M. E. Smith, and R. Heimlich. 2001. Environmental indices and the politics of the Conservation Reserve Program. *Ecological Indicators* 1:11–20.

Shabman, L., and K. Stephenson. 2000. Environmental valuation and its economic critics. *Journal of Water Resources Planning and Management* 126:382–388.

Smith, V. K. 1996. Estimating economic values for nature: Methods for non-market valuation (new horizons in environmental economics). Edward Elgar, Brookfield.

US EPA. 2000. National air pollutant emission trends 1900–1998. EPA 454/R-00-002. Report available at http://www.epa.gov/ttn/chief/trends/trends98/.

US EPA. 2001. 1999. Toxics Release Inventory: State Fact Sheets. EPA 260-F-01-001. See also web site: http://www.epa.gov/tri/.

US EPA. 2003a. Index of watershed indicators. Office of Wetlands, Oceans and Watersheds. http://www.epa.gov/wateratlas/geo/maplist.html.

US EPA. 2003b. Green book. Office of Air and Radiation. Office of Air Quality Planning and Standards. www.epa.gov/oar/oaqps/greenbk/baltimo.html. Last updated 6/26/2003.

Woodley, S., G. Alward, L. I. Gutierrez, T. Hoekstra, B. Holt, L. Livingston, J. Loo, A. Skibicki, C. Williams, and P. Wright. 1999. North American test of criteria and indicators of sustainable forestry. USDA Forest Service. Inventory and Monitoring Institute Report No. 3.