Establishing Empirical Bases for Sustainability Objectives

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Abstract—*The argument is made that sustainability should be construed as measurable environmental conditions, and that sustainable development strategies should be considered in terms of how well they contribute to the sustainable condition target. A case study of the Chesapeake Bay is presented to illustrate how use of Material Flow Analysis (MFA) as a basic component in the proposed sustainability methodology serves to coordinate and harmonize information. Observations are presented on the MFA-Sustainability methodology pertaining to its harmonious accord with existing regulatory structures and the risk assessment paradigm.*

Introduction

As a general goal, sustainable development is a big tent under which all people of good will can discuss and debate options for advancing the human enterprise without excessive concern over definitions or metrics. In contrast, any effort to organize information to advance sustainability objectives is immediately weighed down with niggling details and debates over scale, scope, and system boundaries. Any notion of "sustainability"- if there is to be any difference between environmental protection as usual and conditions that can be arguably defended as sustainable over time - has to be built upon empirical limits and definitions of scale and place.

By its nature a "holistic" and multidisciplinary ideal, sustainability is a multivariate tangle of scale and issue complexity. An effort to establish empirical foundations and to assign metrics necessarily entails system boundaries and some measure of reductionism, introducing what might appear to be a cross-purpose between the holistic ends and reductionist means. This constitutes a challenge in devising a methodology to address sustainability as a quantifiable outcome while preserving the complex and multifarious qualities represented.

For clarity in discussing sustainability objectives, sustainability can be thought of as the goal for which we are attempting to fix a quantifiable condition or characteristics, and sustainable development is the process of achieving it through policy, law, technology, and strategic objectives (Clift 2000). Sustainability needs to be first characterized as conditions for which some defendable criteria are established, and sustainable development is then the process whereby some subset of the human enterprise is managed to enable the attainment of the sustainable conditions. If sustainability is to represent an improvement over environmental protection as we know it, we need to know what conditions are desirable to sustain. Otherwise, in the absence of an identified endpoint, any improvement can be represented as success. While this may be all to the good, it does not necessarily represent progress toward sustainability, and functionally robs the concept of sustainability of its essential distinction.

Definitions of sustainability traditionally subdivide the overall goal into environmental, social, and economic dimensions, each with metrics suitable to their respective objectives (NRC 1999). Social and economic objectives are subject to widely differing value judgments with the result being a broad range of desired conditions – some conflicting. In contrast, acceptable environmental conditions are more easily characterized, as they are set essentially by physical and natural laws relating to conditions that support life, that can with diligence be reasonably ascertained. Environmental condition is as a result, better suited to empirical debate and definition, and is a logical choice to model an empirical methodology. Social and economic conditions of sustainability, while equally essential, are most effectively introduced as criteria for selecting sustainable development strategies to meet prescribed ecological conditions.

Discussion

Recognizing that many different approaches have been taken to evaluating sustainability strategies, and that in some instances methods have been thought to be competitive or mutually exclusive, efforts to examine how these approaches relate to one another have been undertaken. Robert offers a 5 level framework for planning in complex systems that is helpful for organizing one's thinking so that comparisons of method and strategy can be more systematic (Robert 2000). His framework distinguishes between actual conditions in the biosphere, goals for biosphere conditions, processes for establishing target conditions, actions, and tools.

Robert's framework is simplified for purposes here to distinguish simply between sustainable conditions giving rise to the idea of empirical endpoints; and the means to those ends – programs, technologies, strategies and the like, that can only be regarded as more or less contributing to that sustainable condition. With an empirical understanding of a sustainable endpoint, methods can be inferred to characterize and measure steps necessary for achieving the desired condition/s. The methods to achieve it can be quantified as to their effectiveness by the measurable extent to which they contribute to the sustainable condition.

Sustainability endpoints share an overarching purpose to quantify conditions suited to preserving life; however, context dictates that endpoints vary wildly across scale, geography, culture, time and economy. This presents a difficulty in assessing the adequacy of, or feasibility of sustainable development recommendations using any kind of rigid analysis. Though process engineers are making considerable progress nailing down the particulars of assessment metrics for "sustainable" technologies where mass and energy outcomes are quantifiable and thus comparable, sustainability questions run to far more complexity (Sikdar 2003). The distinction highlights the difference between identifying sustainable development strategies leading to sustainable conditions, and optimizing between competing technologies or strategies. In the first instance, one determines minimum necessary conditions to sustain life based on identified criteria. In the second instance, one is optimizing an outcome by comparing strategies or technologies using identified criteria that may or may not be sufficient to maintain a sustainable condition. Linking the outcome of the second to the criteria of the first establishes a logical sequence for modeling sustainable development practices and sustainable conditions.

It is tempting to conclude that addressing sustainability across the physical, cultural, and economic geography can only be dealt with by keeping analysis scaled locally or regionally to reduce complexity. While this is appropriate for a large range of sustainability questions, such as "how much water can we consume from this source" or "can we develop a sub-division in this aquifer recharge area?" it does not work for many other questions. Issues such as "is hydrogen a suitable fuel for transportation, such that it makes sense to build a national infrastructure to support it?" or "Shall we legislate federal guarantees for insurance on buildings build on barrier islands?" can not be addressed on a local scale. The whole range of questions relating to the use of materials (particularly persistent, bioaccumulative and toxic (PBTs) in a global economy, and nationally legislated (dis)incentives can only be addressed on the most comprehensive and national/global scale.

These are more thorny problems of nesting sustainable development strategies (including sustainable technologies) so the piece-meal decisions that necessarily constitute the human enterprise can be evaluated in light of how well they serve ecological, social and economic endpoints (How does this technology serve sustainability objectives?). The systems level sustainable condition target is necessary for guiding decisions about any undertaking entailing significant resources to move the human enterprise toward sustainability. We appreciate that decisions leading to the large commitment of resources can result in tremendous shifts of material and energy with significant implications for sustainability of national and global ecosystems. Failure to shape such decisions with an eye to serving sustainable endpoints, while recognizing their planet-wide implication is a feature of the last millennium and one we can no longer afford to indulge. How to motivate this sort of analysis and behavior is elusive.

It is desirable that an assessment methodology for sustainability be available that allows an analysis to peer into the future of an enterprise, and to envision the affects to target systems based on reasonable projections. The methodology would need to be flexible so that it could be tailored to individual applications, but could provide comparable information between options. Most importantly it would need to be designed around the availability of information, and not be so information intensive as to be overly burdensome or expensive to use.

Brunner and Starkl offer a pragmatic overview of "off-the-shelf" decision support methods with an approach that holds economic, social, and ecological criteria equal, so that a qualitative social criterion such as broad democratic participation in the decision making is considered along-side rigorous biogeochemical criteria pertaining to ecosystem health (Brunner and Starkl 2004). While useful in its own right, it illuminates by contrast the value in formulating a methodology that first identifies sustainable conditions in the environment, and then evaluates social and economic strategies to meet them. This conforms to the model advanced above of first identifying sustainable conditions, and then applying social and economic criteria to optimize technology and strategies to attain the target conditions.

The challenge is in developing a methodology that meets the following criteria:

1. Is empirical (transparent process and reproducible) and follows a logical and generally agreed-to framework.
2. Allows flexibility among various applications and different scales (multidisciplinary).
3. Permits connectivity/integration between multiple models and methods, as well as comparison between strategies to effect sustainable practices.
4. Captures data useful for characterizing the health of the environment, as well as social and economic conditions, while minimizing need for new information collection.
5. Easily adopted by existing social and business institutions.

Proposal

Many strategies to characterize, quantify, and measure sustainability have been published, and numerous means to organize them proposed. The Material Flow Analysis (MFA) is one strategy among many, however, it offers an important feature key to characterizing sustainability as conceived above. MFA is a quantifiable analytical tool, and it describes conditions of material flowing through the environment and by extension, the economy – and society. Examples include important resource flows for national economies, feed stocks for manufacturing and production, and naturally, elements/compounds in circulation or sinks in natural systems. A MFA yields a picture, dynamic through time, capable of characterizing any condition or source of stress to the environment, economy or society (as construed through demographic data) when relationships are properly understood. In a model, MFA data can be used to test proposed changes to material flows based on various sustainable development strategies under consideration (NRC 2003). The MFA is well suited as a foundation, or center-piece to support an empirical methodology for sustainability, as it meets elements of all five criteria identified above.

It is proposed that the MFA serve as both an anchor for an empirical sustainability methodology as well as an organizing point of origin around which to assemble various analytical tools for various sustainability investigations. To describe this process, I begin with several assumptions already discussed. First, the environmental conditions desirable to sustain are already characterized using ecological indicators that can be expressed in terms of material flows.

Secondly, sustainable development strategies are identified to meet sustainable conditions. Environmental criteria (linked to material flows) are identified. Social and economic assessment criteria are also introduced at this juncture to fully optimize sustainable development options.

Thirdly, a set of analytical and decision support tools are selected by decision makers and their technical support teams. There will be substantive variation among sustainability inquires leading to a wide variety of tools suitable to various investigations. The utility of the MFA is once again apparent as a common foundation across different assemblages of analytical tools providing a unifying link among different investigations. The extent to which formal guidance can be provided by an authoritative body to improve scientific rigor and comparability of results across all sustainability investigations is a subject for further study, but is predicated on the idea that within this approach they will follow in some logical way from use of a MFA.

The Chesapeake Bay, centered primarily in Maryland, is offered as a case study for application of the MFA approach; its indicators of condition being dissolved oxygen, water clarity, and chlorophyll a.

A Case Study

The Chesapeake Bay is the largest estuary in the United States. It is roughly 200 miles long stretching from Havre de Grace MD, to Norfolk, VA, with over 11,600 miles of shoreline (greater than the entire shoreline of the West Coast). The watershed is approximately 64,000 square miles, and includes all of the District of Columbia and parts of six states (Maryland, Virginia, West Virginia, Delaware, Pennsylvania, and New York).

As with all bodies of water in the United States, the goal for the Chesapeake Bay, as provided for in the Clean Water Act, is to "restore, and maintain the chemical, physical, and biological integrity" (US Code). The US Environmental Protection Agency (EPA) provides guidance to the States and Tribes for the determination of designated uses and assessment criteria, and provides oversight to ensure that the States and Tribes designated uses and criteria are consistent with the Clean Water Act (CWA).

As the Nation's waters have been increasingly protected from toxic point sources of pollution, the annual reporting by EPA and the States (CWA 305-b & 303-d) rank excess nutrients and siltation as the two leading causes of impairment to water quality. This is true as well for the Chesapeake Bay.

In 2000, EPA began publishing CWA section 304(a) water quality criteria to assist States and Tribes with addressing problems associated with excess nutrients. EPA has recommended that states used its guidance as a starting point for developing refined regional and site-specific criteria for the protection and attainment of designated uses. To assist states in the Chesapeake Bay watershed as they work to address nutrient pollution as well as sediment pollution, EPA Region III issued guidance in 2003 (CWA 304-a) with a refined set of criteria for the Chesapeake Bay (US EPA 2003a). These criteria were developed to protect five designated uses which EPA identified and described based on the types of habitat that exist in the Bay. The five habitats – shallow water, open water, deep water, deep channel, and migratory and spawning areas – allow the water quality standards to be matched with the plants and animals that are adapted to life in those different areas, rather than on a single bay-wide standard (Chesapeake Bay Program 2001). The water quality criteria selected for characterizing and monitoring the Chesapeake Bay are dissolved oxygen, water clarity and chlorophyll a. The criteria collectively provide the best and most direct measures of the effect of excess nutrients and sediment pollution on the Bay's living creatures, thus allowing for the direct measure of environmental endpoints.

Placing this information in the context of the proposed MFA methodology, we have established that the Chesapeake Bay has been characterized using ecological indicators that reflect material flows of nutrients and sediment, per the first assumption identified in the proposal above. These criteria can then be directly linked to necessary reductions in the flow of air, land and water based loadings of nitrogen, phosphorus and sediments through the application of air shed, watershed and tidal-water quality Bay models and long-term water quality monitoring data records. Essentially, the conditions necessary for attaining the three sets of water quality criteria established for the Chesapeake Bay can be directly related to limits on nutrient and sediment loadings. In turn, these loadings can be allocated to sources and specific locations with the watershed.

Thus, we see how a stated goal, the protection of living creatures within the Chesapeake Bay, can be characterized such that specific materials – nitrogen, phosphorus, and sediment, can be examined as material flows into and through this ecosystem affecting the goal of protecting the organisms within the system. The MFAs necessary for managing the ecosystem were determined through studies linking causes of ecosystem distress to the excess of specific materials in the system.

Assumption two dictates that the criteria established for sustaining the conditions of the ecosystem (or systems) in question are used to vet strategies for attainment of the sustainable conditions. Now, in turn, the MFA becomes the foundation for shaping subsequent analysis of strategies to limit the flows and thus achieve a sustainable condition for the ecosystem.

It is important to appreciate that the methods employed in determining sustainable conditions are qualitatively different from those appropriate for optimizing sustainable development strategies. Whereas a sustainable condition is fixed (although may be represented as a range based on uncertainty), comparing sustainable development strategies may employ the many proposed sustainability metrics that rely on indices where a "score" can be derived. Sustainability metrics include measures of material used, waste created, toxicity, water, and energy consumed, and cost, as well as those identified for Chesapeake Bay water quality (Sikdar 2003). Scoring options with a set of metrics describes moving along a linear path toward sustainability. Creating the largest positive score and minimizing negatives allows one to score a sustainability index that can be comparatively evaluated. This is useful for comparisons, but unless a sustainable condition has been identified, lacks a context for determining adequacy. Without an empirical sustainable condition target, sustainable development metrics are unable to answer the question: "Is this a sustainable strategy/technology/product?"

Increasingly, ecologists and managers have at their command models, tables, reference data, and other empirical information that enables estimates, with known levels of uncertainty, to be made for the effect of various strategies to control the delivery of pollutants to specific ecosystems. As the literature grows the information is ever more transferable through models and other expert systems to provide decision support to the management of any ecosystem of concern. While the models and their transferability are far from infallible, ecosystem research is making steady gains and developing a comprehensive literature to describe ecological condition (Heinz Center 2002).

In the Chesapeake Bay watershed two models are used primarily to evaluate different options for the management of the ecosystem and control of nutrients and sediment. The Watershed Model is designed to simulate nutrient and sediment loads delivered to the Bay under various management scenarios and features a simulation of overall mass balance of nitrogen and phosphorus in the drainage basin. Input nutrients are simulated to be transported to any of three end-points: incorporation into plant material, incorporation into the soil, or loading to the Bay through river runoff (Donigan and others 1994). The Chesapeake Bay Water Quality Model features a 3-dimensional equation of the water column simulating the movement (and barriers to movement) of the three criteria for Bay water quality: dissolved oxygen, water clarity, and chlorophyll a (Wang and Johnson 2000). Together, the models are used to characterize the movement of nutrients and sediment into the Bay and their effect on the environmental criteria used to assess the sustainability of the water quality and living creatures in the five different designated uses (or habitats). Managers and decision makers equipped with this information are able to consider options to reduce the level of pollutants flowing into the Bay using various decision assistance tools. Checks against field monitoring data show deviation in the models from actual conditions, and consequently they are being refined. The targets for sediment and nutrient runoff into the Bay, newly established to meet the condition targets are 4.5 M tons/year for sediment, 87,500 tons for nitrogen, and 6400 tons for phosphorus (Chesapeake Bay Program 2003). States are using these goals to further develop and hone strategies for reducing sediment and nutrients into waterways.

Germane to assumption three, EPA's methodology built around the MFA characterizes other tools that can usefully be employed to use the MFA data in subsequent analysis to inform the sustainability goal/question. EPA Region III and the National Center for Environmental Economics identified additional analytical tools to round out the assessment of different pollution management scenarios on Bay water quality employing socioeconomic criteria (US EPA 2003b). Using data and assumptions established in the literature, EPA provides estimates of the annual cost of achieving controls based on the water quality criteria using best management practices. EPA then populated a socioeconomic model to determine the effects of various management scenarios, such as economic growth and revenues, employment, income, and investment. Selection of these tools was based on commonly held expertise informed by empirical information describing the effect of different management scenarios on the material flows of nutrients and sediment in the watershed.

A presentation of data resulting from the assemblage of models and other analytical tools is not possible within the space limitations of this paper; however, it should be known that as public information they receive rigorous scrutiny from advocacy groups and affected parties of all stripe. The constructive engagement of the public with expert information is a critical dimension of any sustainability initiative. Means to organize public values and recommendations into the decision making process is acknowledged to be an essential element of a sustainable development.

Observations

Sustainability Objectives Can Be Empirical

If you don't know where you are going any path will take you there - to paraphrase one of Carroll's creatures in his tale "Alice in Wonderland." While developing metrics to compare various sustainable development strategies for general conservation and toxicity purposes is necessary, it is not sufficient. The identification of a sustainable condition as a target is necessary to determine sufficiency of a sustainable development strategy. Using the MFA approach requires first parsing the scale issue to determine if the methodology is oriented toward a discrete place, such as with the Chesapeake Bay example above, or if it must extend to an unbounded (or global) geographic assessment, such as would be the case when considering persistent, bioaccumulative toxic substances. Following a determination of suitable scale to address the sustainability question, an investigation or set of inquiries is structured to yield identification of a suitable MFA that will characterize a flow/s relevant to characterizing the conditions of sustainability in the system under question. This phase of the methodology development will yield an empirical sustainability target condition. The next phase of the methodology development will be to characterize and assemble the decision support tools that will enable an assessment of sustainable development strategies for attaining the target condition.

The US Environmental Protection Agency's Science Advisory Board, an independent scientific review board for EPA, proposed a process very much like that described here in their 2000 publication "Toward Integrated Environmental Decision Making." Asked by EPA to update their groundbreaking report "Reducing Risk"(US EPA 1990) the SAB formed a committee with over fifty additional Ph.D.s to address the general question of how to update and extend the thinking about how science can best inform the decision making process (USEPA 2000). The integrated environmental decision making (IED) framework proposed by the SAB relies heavily on establishment of goals, use of the risk assessment paradigm (NRC 1983) and comparison of possible management scenarios by analyzing decision criteria. Key in making the assertion that the SABs IED is comparable to the sustainability methodology proposed here is the phrase repeated throughout their publication: "analysis of the economic and societal consequences of various options is an important aspect of options analysis." SAB makes the leap from environmental decision making to sustainability through asserting the necessity of including social and economic dimensions in the analysis of management options. In addition, I propose only that the MFA plays a key and critical role in organizing information essential to determining ecological condition.

The similarity to SAB's IED is important because the IED was viewed by the SAB scholars as "the next step" in improving environmental decision making. SAB's first of ten recommendations was "EPA should continue development of integrated, outcomes-based environmental protection, while maintaining the safeguards afforded by the current system." To this I add that the established regulatory process for environmental protection is a foundation upon which empirical sustainability can be built. Laws may need to be amended, and public process greatly enhanced with requirements for broader social assessments, but the basic building blocks of fact finding, scientific research, regulation setting, and voluntary compliance are sound footings on which to build sustainability.

An Empirical Approach to Setting Sustainability Objectives is a Seamless Extension of The Existing Regulatory Process and Approach to Environmental Management

As was illustrated with the example of the Chesapeake Bay, existing statutory approaches to protecting the Bay environment (ecosystems) have been employed to establish an empirical understanding of the conditions necessary to protect the habitat of organisms considered to be indicators of the sustainability of the Bay's health. This approach arises directly from the law governing US water quality and the flexibility afforded the EPA in working with the States to tailor the law to localized conditions. Another example is implementation of the Total Maximum Daily Load (TMDL) provision of the Clean Water Act which permits the EPA to look at total limits to a receiving waters capacity for absorbing pollutants in setting facility effluent permits, and thus enabling a ratcheting down of permitted pollution below effluent standards otherwise allowed. These examples illustrate that the use of existing mandates and regulatory stratagems enable the determination of empirical sustainability objectives. Only the means for compulsory attainment are not in place, however they represent nothing more than stricter standards.

The Risk Assessment Paradigm Offers a Constructive Platform from Which to Establish an Empirical Foundation for Sustainability

US EPA's policy on the use of human health and ecological risk assessment reflects growing reliance in this paradigm for ensuring a sound scientific foundation for environmental protection and regulation. The development of uniform guidelines for risk assessment, as formulated over the past 20 years, has yielded rigorous techniques for analyzing threats to human and ecological health that can be harnessed for examining how to also optimize them. The use of risk assessment, pioneered for health applications at EPA, has been adapted for use in determining risk to various features in ecosystems and choosing the best actions to protect them. Ecological risk assessment is a process to collect, organize, analyze and present scientific information for use in making decisions about environmental protection priorities. This is performed by evaluating the likelihood that adverse affects are occurring (or may occur). Risk assessment techniques provide a basis for comparing, ranking, and prioritizing risks, and estimating ecological effects as a function of exposure to stress in the environment – important functions embraced by SAB's EID. The function of a risk assessment in the MFA-based sustainability methodology is to ensure that the materials selected are in fact critical to understanding the function and health of the target system. In the Chesapeake Bay, selection of chlorophyll a, water clarity (or turbidity) and dissolved oxygen was based on substantial research showing correlation to nutrient and sediments loads to the Bay. Under circumstances less well substantiated, risk assessment tools provide a means to conduct a sensitivity analysis of materials being used to target sustainable conditions in a system, and to ensure that they will accurately reflect system health. A risk assessment to identify significant anthropogenic stressor/s in the Waquoit Bay demonstrated the utility of this approach (Serveiss and others 2004).

EPA supported the application of risk assessments to five pilot watersheds to ascertain the value of the risk paradigm to watershed management. In a report analyzing the use of ecological risk assessment methods for watershed protection it was found that watershed management benefits from the use of the formal, scientifically defensible methods of risk assessment by providing a process to help people examine their assumptions and conclusions, and to document their findings. The risk assessment framework is particularly valuable when addressing problems caused by multiple and non-chemical stressors (Eastern Research Group 1998).

Risk assessment principles can, be applied to provide insights on monitoring data collection, how to organize data, or formulate a problem. The application of this process for identifying sustainable conditions and evaluating sustainable development strategies for meeting them is straight forward, consistent with the use of MFAs, and further illustrates how existing means for environmental protection can be employed to effect the identification of sustainable condition objectives.

The Quality of Information, and Its Intensity, is Subject to Challenge

Information quality in any enterprise with claims to an empirical foundation is fair game for challenge. This is especially true in characterizing the health of ecosystems where each place is unique, variables are virtually infinite, and the science is far from unanimous. Until the present, government efforts to discern the weight of evidence followed the often messy path of scientific discovery relying on expert judgment – with that subject to the imprimatur of prestigious associations. This is a less certain environment today with the promulgation of data quality rules by the Office of Management and Budget (Weiss 2004). Scientific certainty is not a luxury often associated with advanced ecological research. Although the legal record on implementation of the Data Quality Law is still inchoate, it could undermine the use of MFA and related analytical tools to define sustainability objectives as a result of too great an uncertainty associated with the data. A consideration of the data intensity associated with bringing a measure of empirical rigor to setting sustainability objectives is also a reasonable concern. Recognizing that even perfect information may not carry the day in decision making, and that political (including popular democracy) and economic considerations may overshadow scientific information, it is fair to ask what level of resources is practical to derive empirical sustainability objectives. These questions should help inform future explorations of this proposal.

Summary

Sustainability is a desired endpoint requiring a degree of planning to achieve, and thus, societal coordination of the type afforded by government is unavoidable. The MFA-Sustainability methodology is not proposed as a shortcut to understanding sustainability; rather, it is an organizing methodology useful for coordinating empirical information to define sustainability and compare options in the contexts of place and identified risk. There is a need to make sustainability an empirical condition respecting of the biogeochemical conditions of a suitably scaled region. Any other approach to characterizing sustainability is subject to changing definitions and is difficult to defend empirically. The power that comes with designing empirical bases for determination of sustainable conditions and sustainability strategies is necessary to optimize the clarity and persuasive power of sustainability recommendations, and to ensure that policy is systematic and transparent. Because of the qualities inherent in the MFA it is presented as a core investigative tool for refining an empirical sustainability methodology oriented toward identifying and prioritizing actions to meet sustainability goals.

There is still a prodigious amount of study necessary to refine an approach to developing a MFA-based methodology for characterizing sustainability as a measurable condition (or outcome). Important considerations include the cost-effectiveness of the methodology, data quality constraints, and available means to build or access material flow data-bases. The NRC study recommends a national body to collect and organize the data.

Perhaps most important is to recognize that existing strategies employed by governments to protect environmental quality, such as regulation and the risk assessments that underlie them, can be harnessed to serve the purposes of defining sustainable conditions and to assessing the relative merit of sustainable development strategies for attaining them. Consideration of where existing environmental law enables pushing the envelope toward sustainability provides fertile ground for further exploring the feasibility of this approach.

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