Sustainability, Indicators, and Institutions of Higher Education

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ABSTRACT

Indicators of commitment to sustainability commonly applied to institutions of higher education provide no estimate of the actual effects that these institutions have on the persistence or prevalence of the socioecological systems that encompass them. Emergy methodology provides a theoretical framework for addressing this practical oversight based on its fundamental insight into the interdependence of the long-term prevalence of any system with that of the broader network of mutually reinforcing resource flows that support it. Our limited ability to predict long-term prevalence in systems characterized by innovative resource flows supported by a pulse in the depletion of available energy storages requires explicit recognition during indicator development and application. Accordingly, conventional emergy syntheses of critical resource fluxes must be supplemented by indicators sensitive to the distinction between pulse-amplifying and resource-reinforcing fluxes of alternative energy resources. Institutions of higher education are of particular interest due to their pivotal role in generating the information flows required in making distinctions of this nature that are appropriate to different stages within the pulsing cycle of a system. This paper considers challenges and opportunities associated with this role and highlights the technical challenge of quantifying effects (on resource allocation patterns and preferences in socioecological systems) of products of higher education that derive from the information flows and signaling associated with education, basic research, innovation, and degree granting. Despite these challenges, institutions of higher education can enhance their contributions to sustainability through programs designed to help both individuals and institutions assess the balance of their amplifying effects on potentially sustainable resource uses with their more generally pulse-amplifying effects.

INTRODUCTION

Current frameworks for assessing sustainability in relation to institutions of higher education focus primarily on their commitments 1) to reducing resource consumption by their programs and operations and 2) to educating students on the possible environmental consequences of current patterns of resource use. Possible indicators of sustainability are readily derived from quantitative measures of these commitments and, in a more limited manner, of their attainment. Relations between these indicators and sustainability in the form of long-term prevalence (or mean relative abundance, herein defined as the relative capacity of a system or process to acquire the resources that support it, whether directly or systemically) remains largely conjectural. The critical but poorly quantified roles that institutions of higher education play in promoting or impeding global sustainability (Rees, 2003; Oppenheimer et al., 2008) heightens the challenge and the need to establish a sounder basis for our assessments, with a particular emphasis on the effects of higher education on the long-term prevalence of our broader socioecological systems. Emergy theory might offer a useful perspective on these problems, given its emphasis on the need for an integrated assessment methodology that accounts for the interdependence of the long-term prevalence of any system with that of the broader systems that encompass it within a network of mutually reinforcing resource flows (with resource values typically quantified in units of solar emergy).
Assessing Contributions of Higher Education

The contributions from institutions of higher education to the sustainability of humanity are multidimensional and often indirect. Economists have long sought to quantify both the direct and indirect effects of education, with widely divergent results. Estimated private non-market benefits of education, however, have been largely positive, as illustrated in Table 1; public costs and benefits have proven more difficult to assess (Lange and Topel, 2006). These studies do not provide very precise estimates even of economic value, but they can provide some direction to our search for relations to consider in assessing and improving the role of higher education in promoting sustainability.

For instance, sustainability assessments are incomplete if they do not account for the positive associations of higher education with such contributors to social stability as civic engagement, literacy rate, and reduced crime (Lochner and Moretti, 2004). Although the importance of these effects on sustainability is widely recognized (McMahon, 2009), they are much more difficult to quantify, whether using emergy syntheses or economics, than are similar positive associations of higher education with measures of short-term economic prevalence (i.e., relative prices, productivities, and employment rates). Similarly, while concerns that socioeconomic inequality can be exacerbated by institutions of higher education (Greiner et al., 2004; Hendel et al., 2005; Alon, 2009) and that increased productivity has been achieved in part through accelerated depletion of our resource base (Bawden, 2004) are both well-established in the sustainability literature, quantification of the net effect of higher education on socioeconomic equality remains more of an ideal than a concrete goal.

The more general difficulty for these assessments is that sociopsychological dynamics (e.g., the dynamics of human preference generation and fulfillment) are so poorly understood (Bowles, 1998; Bradley, 2007; Fehr and Hoff, 2011). Although much modern economic theory seeks to explain the dynamics of equilibration (against countervailing tendencies) between contributions to and requirements for preference fulfillment (especially as measured and mediated through purchasing power in relevant markets), little progress has been made in integrating this understanding within a more general and complete model of human behavior that includes preference generation, amplification networks, and limiting factors, for instance. In this regard, the relations of the coupled flows of purchasing power and socioecological system productivity to long-term cycles of expansion and decline have a particular relevance to the establishment of reliable indicators of survival or sustainability values (Odum, 1994, 1996; Lonergan, 1998, 1999). Despite our limited progress in quantifying these fundamental determinants of socioecological system performance and sustainability, it remains qualitatively clear that higher education plays an important role—for better or worse—in shaping human preferences (and social goals/values), in realizing these many common (albeit often conflicting) goals through human capital formation and innovation, and in assessing and reinforcing resource-use patterns in accordance with these preferences and goals.

Until these effects of higher education are better integrated with the long-term goal of achieving resource acquisition patterns capable of supporting sustainably flourishing communities, their contribution to promoting sustainability will be greatly diminished by the many conflicting goals that they simultaneously support. In the meantime, whether or not increases in productivity and global resource depletion that are simultaneously amplified by education will eventually reinforce global resource acquisition in a sustainable manner (thus representing a useful pulse) remains a widely debated question (Schumacher, 1974; Rees, 2003; Bawden, 2004; Cortese, 2008) with critical implications for the reliability of sustainability assessments.

Selection of Sustainability Indicators

Stage-appropriate indicators

Higher education institutions and programs, like other socioecological systems and components, develop in stages that present distinct challenges with respect to sustainability. In initial stages of organization (or following a major setback or downturn), most institutions must (re)establish a reliable
Table 1. Non-Market Benefits of Higher Education.

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Own health</th>
<th>Spouse's health</th>
<th>Child health</th>
<th>Lifelong learning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Econ. value ($/yr)</td>
<td>16,800</td>
<td>1,917</td>
<td>4,340</td>
<td>&lt; obsolescence</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Job and location amenities</th>
<th>Child educ./development</th>
<th>Consumption and saving</th>
<th>Total private nonmarket benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Econ. value ($/yr)</td>
<td>positive</td>
<td>7,892</td>
<td>3,401</td>
<td>38,080</td>
</tr>
</tbody>
</table>

Data from McMahon, 2009.

comparative advantage in the production of a value- or resource-amplifying contribution to their supporting system by tapping a previously “underexploited” resource. The great risk of short-term failure may dominate sustainability concerns at this stage, with little thought given to whether the new exploitation is itself sustainable, or whether it promotes or undermines long-term persistence of supporting systems. In later stages, institutions often have developed reliable patterns of resource acquisition along with a reserve of resources that can sustain them through temporary setbacks or permit them to invest in substantial improvements to program efficiency or competitiveness. Sustainability concerns focus on maintaining their established niches (or comparative advantages) and optimizing returns on resource allocations to further expansion and to long-term sustainability (persistence or prevalence). They often can invest in sustainability out of their abundance, rather than solely out of their need.

Indicators for an institution should vary accordingly depending on its stage of organization. An effective sustainability program should include a dynamic cycle of indicator selection and refinement based on a continuous monitoring and goal-setting process. During initial stages, some of the most basic indicators can be used to monitor the institution's operational performance (e.g., energy consumption or emergy flow from renewables and nonrenewables) along with its progress toward establishment or realization of a comparative advantage based on sustainable, resource-reinforcing production. As the institution develops, further indicators of performance in terms of quality of investment for long-term sustainability (e.g., natural and human capital formation, contributions to community well-being, system-monitoring information flows, etc.) would be appropriate. Development of institution-level indicators that reflect effects of the institution on specific sustainability goals at the broader level is also appropriate for more established institutions that have the resources to pursue the need for this type of sustainability indicator.

Selection criteria

Although each stage in any system may require indicators specifically suited to that particular stage, criteria for selecting a set of suitable indicators are similar. Useful assessments use indicators that are 1) on target, capturing the important aspects of the institution; 2) sensitive, consistently responding to changes in important parameters; 3) easy to measure and/or calculate and understand; and 4) integrative of multiple aspects of system sustainability. These criteria can help guide the selection process.

Scenario-based indicators can also enhance the usefulness of an assessment by providing a range of values estimated under more optimistic or less optimistic scenarios. For example, alternative trends in growth rate or resource use and depletion can be estimated based on a projected range of developments in culturally driven consumptive demand, technological innovation, and government policy (Millennium Ecosystem Assessment, 2005). Such scenario-based estimates can quantify some of the uncertainty associated with sustainability indicators, such as in estimating or predicting resource flows and dependencies; technological changes; adaptation and selection pressures; and environmental, social, and economic thresholds, but they often fail to provide clear guidance for our most pressing management and policy concerns. Thus, although they retain an essential role in sustainability education and decision making under uncertainty, they would be more useful if complemented by a systematic analysis/synthesis of relations among resource uses and amplifications (Odum, 1994).
APPLICATIONS OF AN EMERGY PERSPECTIVE

Resource Flows Supporting Education Institutions

Sustainability indicators that focus on efficient use of an institution's resources have been derived based on analyses of resource flows to, from, and, to a lesser extent, within the institution (Litten and Terkla, 2007), and a synthesis of major solar energy contributions to a university has been presented by Odum (1996). A more detailed synthesis of these flows (as depicted in Figure 1 for a model university operating according to an institution-defined sustainability vision) would begin to address some of the limitations in current sustainability assessments. The university system responds to external forcing functions: sun, rain, wind, fuels, water, minerals, potential students, goods, services, and teachers, as well as private and government funding and its exchange of cultural capital with outside sources. This capital includes the cultural norms, narratives, and values that shape common goals and perceptions in conjunction with information about system states, relations, dynamics, and performance. Students and cultural capital are the inputs most specifically associated with the role of the university within its broader socioecological systems. In addition, money flows from private (e.g., tuition) and government sources into the university system and is used to pay for services (both those associated with goods and pure services) as well as the salary and benefits of teachers and administrators. The internal components of the university system are the grounds or surrounding environment, buildings, books, equipment, students, teachers, the administration, and new construction. The specifying products of the university are its graduates and dropouts along with the cultural capital generated through scholarly efforts and collegial life and conveyed along with the students as well as through publications and outreach.

In the diagram the university’s vision of sustainability (which typically represents some balance among a number of conflicting goals and perceptions) informs all major processes of the university system, including how the grounds are managed, how new construction and renovations on campus are carried-out, how buildings, books, and equipment are purchased and maintained, how the curriculum is organized, which research and outreach efforts are emphasized, and how the day-to-day operations of the university are accomplished. Such a university system is designed to produce graduates who are prepared to meet the challenges of designing the sustainable environmental, economic, and social systems of the future; research and outreach that further support this goal; and a practical example of the adoption and ongoing refinement of a sustainability vision informed by a “sustainable mindset” (Cohen, 2007; Stephens et al., 2008). Although we are focusing on universities with explicitly defined sustainability visions, resource-allocation decisions are made within other universities as well based on various perceptions of the long-term interests of society and of the university. Such a long-term vision might consist primarily of implicit assumptions about the future and its challenges—for instance, that the mindsets, activities, and programs that have historically sustained society, and the place of the university (and its graduates) therein, will effectively meet human needs and aspirations indefinitely.

Estimates of effects and dependencies among resource flows and alternative allocations based on systems diagrams for a specific institution can provide an initial understanding of the system, its interacting components, and dynamics. These dynamics are responsible for the many indirect effects on sustainability that less integrated analyses (based on large sets of unrelated indicators of resource-use efficiency) can overlook. To evaluate these effects more explicitly, some major flows within the broader socioecological systems (Figure 2) must also be considered. These larger systems operate under their own (explicit and implicit) visions of sustainability based on shared information developed, in part, by educational systems. The university is a core information replicating system, and its graduates also affect the extent to which the other main system components, i.e., the economy and government, operate according to shared social visions, which include the widely accepted goals of the society. Implementation of goals is guided by direct feedback to the main economy and university systems (which can directly influence social ideals and their realizations through innovation) as well as indirectly through government services and control.
Figure 1. System diagram showing the complex interdependence of many factors within and outside an institution of higher education with an institution-defined sustainability vision (SV). Critical flows that can generate a viable niche for such an institution include its contribution to an educated workforce and citizenry and its exchange of cultural capital, which includes mutually reinforcing sociopsychological dynamics as well as research results, with broader systems. The sustainability visions and experiences of these and other institutions are developed within the context of this exchange; they promote or diminish niche viability through their effects on processes contributing to long-term prevalence of resource acquisition by the institution and by the systems that support it.

Possible Contributions of Emergy Theory to Sustainability Assessment

Sustainability according to emergy theory

Emergy theory hypothesizes that empower acquisitions by prevailing systems or processes indicate their respective (but perhaps joint) contributions to encompassing system sustainability when these systems have had sufficient time to adapt to their selection regime (quantifiable in terms of emergy sources). Neither the current socioeconomic system nor the higher education system has persisted long enough, however, for us to conclude that contributions to reinforcement of long-term empower acquisition by encompassing systems are commensurate with the acquisition requirements of higher education systems. At least two possibilities must be considered when this equilibration has not occurred. When requirements exceed contributions, improved sustainability (at all levels) might be sought primarily through improved resource-use efficiency (i.e., less resources used per unit of contributions). Increasing unit contributions of resource use by a university to sustainable resource acquisition by encompassing systems can enhance not only the viability of the encompassing system but also that of the university that it supports. Alternatively, when contribution exceeds requirement, an increased rate of resource acquisition and use could be a more effective strategy for enhancing long-term prevalence, particularly when that contribution selectively reinforces or supports a switch to renewable resource acquisitions from flow-limited sources. Given the highly nonlinear dynamics of these systems, these initial considerations represent merely a first-order approximation.
In the short term, a process or system might prevail (persist) even if its contributions to the broader system do not exceed (meet) its requirements due to a mismatch between resource allocations based on human preferences and those based on net emergy contributions. Although the emergy theoretic perspective suggests that its contributions must eventually meet its requirements in the long term for it to be truly sustainable, it does not tell us whether a system can survive in the short term in the face of unfavorable sociopsychological dynamics. The importance of these dynamics in the broader society for higher education institutions has been the focus of intense discussion recently (predominantly in the popular press) with respect to the sustainability of programs and institutions that fail to provide students sufficient psychologically assessed benefits to match the corresponding costs (in terms of current experience as well as expected long-term debts and rewards). We do not have, however, a reliable and generally accepted method for analyzing these dynamics (or even for determining whether we are currently experiencing a bubble or unproductive frenzing dynamic in the market for higher education); thus predictions of future demand for higher education remain controversial, and assessments of the short-term economic viability of particular institutions remain incomplete. Development of sustainability indicators is critically limited by this unpredictability of sociopsychological dynamics (Juarez-Najera et al., 2010).

The sustainability of resource use by the global socioeconomic system will also affect the sustainability of the higher education system and of each institution within it. Within this global system, and in many individual societies within it, resources allocated to the higher education system have increased markedly, in both absolute and relative terms, for several decades. In assessing whether this increase corresponds with increased contributions to emergy acquisition by some encompassing system, we note the correlation between expanding higher education sectors and increased resource acquisition prevalence across a broad range of societies. The emergy-exchange advantage of societies with well-supported higher education sectors is also particularly noteworthy from an emergy theoretic perspective.

**Accounting for the prevalence of higher education**

Higher education thus possesses the basic traits of components that are becoming more prevalent by contributing more to the emergy acquisition of their encompassing systems than they require from them. Some overshoot (beyond sustainable prevalence) within the most resource-intensive systems might also be expected, however, given the growing resource-acquisition capacity of many competing systems with rapidly expanding education systems within an environment rife with readily duplicated and dispersed innovations. Indeed, higher education in resource-intensive systems already displays traits common to components that are becoming more prevalent in the short term due to unsustainable dynamics in preference fulfillment and related expectations within these systems. In addition to these...
two education-specific trends, an analysis of sustainability as affected by global emergy dynamics must consider the current trend towards a peak in empower acquisition along with the potential for new emergy sources being tapped due to some technological breakthrough.

The uncertainty introduced by these ambiguous traits and trends limits the precision of institution-level sustainability indicators and assessments. In very broad terms, the current trend of increasing enrollment and tuition (with a resulting increase in empower acquisition) might suggest an opportunity for continued investment by the higher education system in infrastructure and programs that are contributing to this short-term prevalence gain. The global trend toward peak empower acquisition could favor investments in efficiency-enhancing investments over the longer term, however, as the potential for capturing an expanding resource flow fades. Individual institutions must make resource allocation decisions based on their own expected enrollment and funding (versus expenditure) dynamics as well as on the broader short- and long-term expectations.

The importance of competitively exploiting a niche, relative to that of generating a niche, within the higher education sector will grow, however, as selection regimes shift from prevalence- to persistence-focused dynamics. In the former case, selective prevalence is often achieved by institutions that develop or discover a comparative advantage with respect to empower acquisition or preference fulfillment. In the latter case, such opportunities become relatively rare, and a sustainable comparative advantage depends increasingly on efficiency in exploiting an existing productive role, leading to the competitive exclusion of institutions that fail to achieve this efficiency.

Sustainability assessment of higher education with emergy accounting

Sustainability assessments are integral to an institution’s resource allocation decisions to the extent that these decisions take into account expected long-term returns (in the form of contributions to the goals of the institution) from alternative resource investments. Emergy accounting permits a quantification of investments in unit emergy requirements for alternative educational and research programs. To address the concern that not all emergy flows are equally sustainable, distinctions among these flows can be introduced based on the projected environmental impacts, competitiveness, degree of dependence on and reinforcement of renewable or nonrenewable resource use, and socioeconomic viability of each flow. A sustainability indicator based on this approach (focusing especially on influx renewability, environmental loading, and emergy returns on investments) has been proposed and developed in some detail as the Emergy Sustainability Index (Brown and Ulgiati, 1997; 2011).

This index integrates several sustainability-related concerns to provide a single-value estimate of sustainability that could readily be applied to alternative resource allocations within an institution. In a decision-making context, the meaning of comparisons based on such integrated indicators depends on which aspects of sustainability are included in the integration, how they are weighted, and the resulting sensitivity and specificity of the index to factors relevant to stakeholder goals. The resulting limitations of any single-value indicator can be addressed in part through complementary indicators more closely related to additional relevant aspects of sustainability. Similar indicators of this nature could accordingly be derived to incorporate a range of perspectives on sustainability. The distinction between renewable and nonrenewable flows, for instance, could be adapted to include additional aspects of the sustainability of resource flows, including controversial aspects such as their social or economic viability. One would obtain, in this case, conflicting sustainability estimates that reflected the highly divergent views that persist on these aspects of sustainability.

The above approach responds to the inability of a purely donor-based measure to account for differences between contributions to resource-acquisition amplification and resource allocation requirements for any given resource allocation, flow, or system that is far from its adapted equilibrium. Estimates for these contributions based on observed amplification patterns must be introduced to credibly address the acute differences in contribution:requirement ratio that might exist among the highly novel and dynamic outputs of an institution of higher education—whether these be research results or unique combinations of education-derived human and social capital attained by students through educational programs.
Our limited ability to trace the effects either of a research result or of these forms of capital (which include personal expertise, information storage and generation capacity, and other attributes that enhance human health, well-being, and productive capacity) on amplification of resource acquisition introduces great uncertainty to these estimates, but they are nonetheless unavoidable within a sustainability assessment. Indeed, as a means for assessing sustainability (or survival value), the standard emergy accounting methodology introduces an implicit estimate that, with respect to long-term empower acquisition, these amplification effects are commensurate with requirements (Odum, 1994).

**Towards a more explicit accounting of amplification effects on sustainability**

In assessing expected reinforcements from resource allocations to alternative research and educational programs, estimates for program viability based on projected enrollment and demand for program-related jobs and technologies in various disciplines might well be supplemented by an emergy synthesis of these jobs and technologies that estimates their respective contributions to the empower acquisition of the broader socioecological systems that support higher education. These estimates would be derived in terms of important relations among higher education, resource use, and amplification of resource use within the supporting system (Figure 3). In addition to monitoring renewable and nonrenewable flows to the institution, the broader effects of higher education on these flows would be included. Within this framework, benchmark measures for indicator development would be provided by relations between resource-replenishing and -amplifying (RA) flows and the potentially renewable resource (RR) flows that use these resources to support economic production, as well as by relations between RR flows and nonrenewable resource (NR) flows. Because institutions of higher education are focal points for critical and innovative information flows that affect the balance between flows that amplify nonrenewable resource use (pulse amplifiers, PA) and pulse-smoothing (PS) flows that, by amplifying potentially sustainable uses of renewable resources, tend to smooth or broaden this pulse, some assessment of this role would be essential to attaining a meaningful set of indicators for the effect of higher education on broader system sustainability. As mentioned above, partitioning the estimated contributions of the products of higher education between renewable and nonrenewable (or more or less sustainable) acquisition reinforcements would provide a long-term perspective on their broader contributions to system sustainability.

Of particular importance both for reducing uncertainty and for enhancing sustainability in a system at near peak or declining empower acquisition is the identification of niches within persistent circuits of emergy flow. These niches coincide primarily with comparative advantages that a component (e.g., an institution) can maintain in production (e.g., of human capital) that reinforces its ability to attract resources (which ultimately derive from empower acquisition). Accordingly, by cultivating expertise in programs for which their opportunity costs can be kept lower than their competitors and which also promote sustainable resource use in the broader society, an institution can greatly reduce the aforementioned complexity of its own sustainability assessments. More generally, institutions of higher education can enhance their own and their broader systems’ sustainability by fulfilling the role of high-transformity producers and disseminators of information on system states and dynamics, with an emphasis on information useful to a more efficient and intelligent linkage of resource allocation, capital formation, innovative explorations, and sustainable amplifications of resource acquisition rates.

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1 i.e., well adapted to current and projected conditions
2 High transformity of higher education and of its products, as calculated in emergy syntheses based on a requirement for support from a broad societal base, implies that some combination of the coproducts of this base must, to be sustainable, contribute a high amplification of empower acquisition by the encompassing system.
Figure 3. Role of human capital in mediating effects of higher education (or learning more generally) on resource flows associated with the sustainability of human systems of production. The contribution of higher education to human capital includes many conflicting goals and perceptions of system performance that influence resource-use and -allocation decisions. Such capital also includes information about fluxes and products within a system that is critical to the formation of these goals and perceptions. (This information storage and its associated flows are depicted in greater detail above the energy systems diagram.) Decisions relevant to sustainability goals, often made without explicit concern for these goals, involve selections made among various resource flows. Of particular importance are selective reinforcements of 1) pulse-amplifying (PA) flows that reinforce nonrenewable resource (NR) uses vs. pulse-smoothing (PS) flows that reinforce potentially renewable resource (RR) uses and 2) system reinforcing flows that reinforce resource-replenishing and -amplifying (RA) flows vs. flows more directly supporting human systems of production.

CONCLUSIONS

Institutions of higher education can enhance their contributions to sustainability not only through the application of conventional sustainability indicators to their own operations, but also through programs explicitly designed to help both individuals and institutions assess the balance of their amplifying effects on potentially sustainable resource uses with their more generally pulse-amplifying effects. Emergy theory has the potential to enhance the assessment of sustainability through systematic syntheses of resource-use dynamics and through a dynamic selection of indicators according to the stages of system adaptation and resource capture. From an emergy-theoretic perspective, the
integration of potentially intelligent, reasonable, and responsible components within a system—however long its previous evolution toward maximum useful energy or emergy influx—can permit further evolution toward goals that are not necessarily compatible with sustainability. The dedication of institutions of higher education to programs that enhance the efficient and intelligent linkage of productive and influx-reinforcing resource allocation with sustainability-compatible goals is itself a key indicator of progress toward sustainability.

REFERENCES


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3 i.e., influx-reinforcing


