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Energy and Water Sustainability: What Do They Mean and Can We Know When We Achieved Them?

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The word "sustainability" has been applied to resources such as energy and water, in addition to products, processes, urban infrastructure such as a city, or a quasi-natural infrastructure such as an eco-system. While there have been reasonable attempts made to evaluate the sustainability status of product and process systems from economic, environmental and societal impacts perspectives, no such systematic or rigorous analysis has been attempted for water and energy as resources, or water and energy supply systems. This discussion covers the essential sustainability concerns of water and energy systems and provides some thoughts on how one evaluates sustainability status and pathways for improvements.

Keywords: *sustainability, energy, water.*

1. Global and Local Concerns about Energy and Water

There is a great deal of understandable worry in recent times about the unsustainability of the business-as-usual exploitation of both energy and water resources. Drastically modifying the current practice is deemed to take us on a path towards the sustainability of water and energy. What changes are needed and whether they will produce the intended effects, however, are utterly confusing. To gain an understanding of what sustainability may mean with respect to energy and water, we need to examine the concerns.

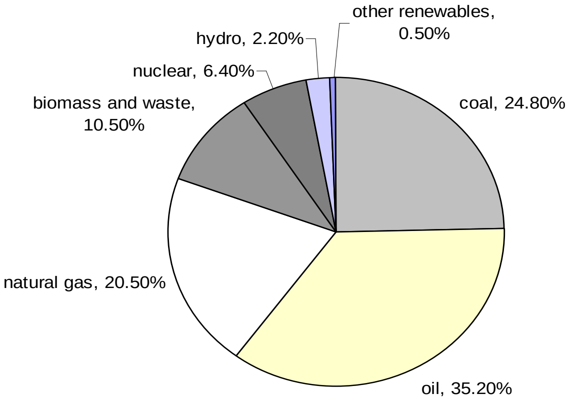

Fig. 1. Global Energy Demand 2006

There are several concerns about energy, the dominant three of which are energy security, climate change, and affordability (Sikdar, 2009). Primary energy carriers used as resources are coal, petroleum, natural gas, and biomass. Radioactive materials such as uranium, potential energy of water, kinetic energy of wind, geothermal, and solar radiation together constitute a minor part of the global energy demand of 11.2 billion tons of oil equivalent. This is shown in Figure 1 (Wall Street Journal, 2007; IEA, 2006). Of the non-fossil energy carriers, radioactive materials, water's potential energy, wind, solar, and geothermal are almost exclusively used for generating power, mainly electricity, although biomass can also be used for power, in addition to being used for transportation fuels and chemical feedstocks. The fossil carriers, i.e. coal, natural gas, and petroleum, find use for power, transportation fuels and chemical feedstocks. Individual country's use portfolio can look very different from the global scenario. For instance, nuclear power is substantial in France, Lithuania, and even in the United States (20% of electricity), whereas biomass is still not a significant part of the energy use picture in the developed countries. The concerns about energy became more heightened recently when the price of petroleum increased to more than $140 dollars a barrel, causing worldwide economic hardships. Whether adequate supply of petroleum can be available in the face of rapid economic growth coupled with a limited number of supplier countries possessing the bulk of the oil resources is the primary cause of energy concern. Of the fossil energy carriers, which constitute more than 80% of global demand, oil alone has a sensitive world market, and natural gas and coal enjoy a more regional transaction. Petroleum however is little used in power generation, that being dominated by coal and natural gas, in that order. Thus the energy concerns are mostly understood in the light of demand-supply picture of petroleum, and the attendant supply disruptions caused by various factors. This then is mainly a transportation fuel issue and the uncertainty of steady supplies makes it an energy security issue.

The second concern about energy is greenhouse gas emission, which is not restricted to just petroleum but all three of the primary energy carriers. The total annual global carbon dioxide emissions currently is about 30 billion metric tons, and the International Energy Agency estimated that business as usual case will increase this to about 40 billion metric tons by 2030 (IEA, 2006) caused by the global energy demand of 15.41 billion tons of oil equivalent. Even with the policy changes that are being discussed currently, the IEA estimate of the energy use portfolio in 2030 remains largely unchanged. Carbon dioxide emission in this intervention scenario would still increase from the current level to 34 billion metric tons of $CO_{2,}$ reflecting population growth and development in the developing countries. Substantial change is expected only in the use of renewables other than biomass, but the expected increase to 2.4% from 0.5%, though impressive, does not alter the emission picture much so as to offer hopes of CO_2-neutral energy in that time frame.

Third concern is the cost of energy, which is more pronounced for the developing countries because expensive energy would invariably stunt their development efforts, making it difficult for increasing living standards of their people. At the moment, the non-fossil sources of power, such as solar, wind, and biomass are mostly not competitive with coal and natural gas. Nuclear can have the scale of generation but this too has its own problems of public fear on account of waste handling and limits to the availability of fissile materials. Many countries around the world have used nuclear power for many years now, and new nuclear plants are arguably affordable.

The first two concerns will drive the development of non-fossil energy carriers for both power production and for transportation fuels in the near and longer term, but eventually the third concern of affordability will determine the attainment of global energy sustainability. In this sense, we have tacitly assumed that sustainability means the attainment of affordable CO_2-neutral energy for power and transportation that is free from international cartels and supply disruption.

Significant changes usually are accompanied by unintended consequences. Non-fossil energy development will encounter two such effects: pollution and health effects potentially emanating from non-fossil power plants and conversion processes for transportation fuels, and shortage of appropriate water needed for these operations in certain arid parts of the world. Not much research has yet taken place on the former, but water for energy development projects will surely compete with agricultural and municipal uses, potentially limiting siting of these energy facilities or limiting growth.

It has been widely reported that half of the entire world population of seven billion don’t have access to raw safe water and about a billion have no access to treated drinking water. Threat to humans on a continuing basis is the greatest from polluted water. One of the UN Millenium Goals (http://www.un.org/millenniumgoals/environ.shtml) is to reduce the number of people without safe water by half by 2012. Taken the world as a whole, water sustainability is a grave humanitarian issue, but from the viewpoint of development also, water sustainability has gained the status of a great concern. In the water arena, the business as usual case has greatly decreased availability of clean water for urban, agricultural and industrial purposes. This situation has revealed itself in polluted surface and ground water and depleted aquifers everywhere. Yet with more urbanization, water needs, following the practices of the developed world, have been steadily increasing everywhere. But water use efficiency can certainly be improved, as can energy use efficiency for all anthropogenic activities. Another significant problem that is amenable to intervention is the amount of water that is not billed for. That is, about 30% of the water delivered is unaccounted for on the global basis. Water governance is a big issue worldwide, as water is delivered free of charge or heavily subsidized, which keep the utilities running at a loss and depriving them of the capital to improve infrastructure. Improvement of transportation infrastructure, i.e. roads, trains and waterways, and adequate storage to reduce spoilage of foodstuff could dramatically improve water use efficiency as well as alleviate food shortage.

Water sustainability and energy sustainability are intertwined, because collecting water always requires expenditure of energy. This entanglement is becoming more intense as safe water is being recovered by necessity from impure, brackish or saline water with the increased need. Figure 2 illustrates the situation for both water and energy footprints on an aggregate national level for selected 21 countries (Hoekstra et al.)

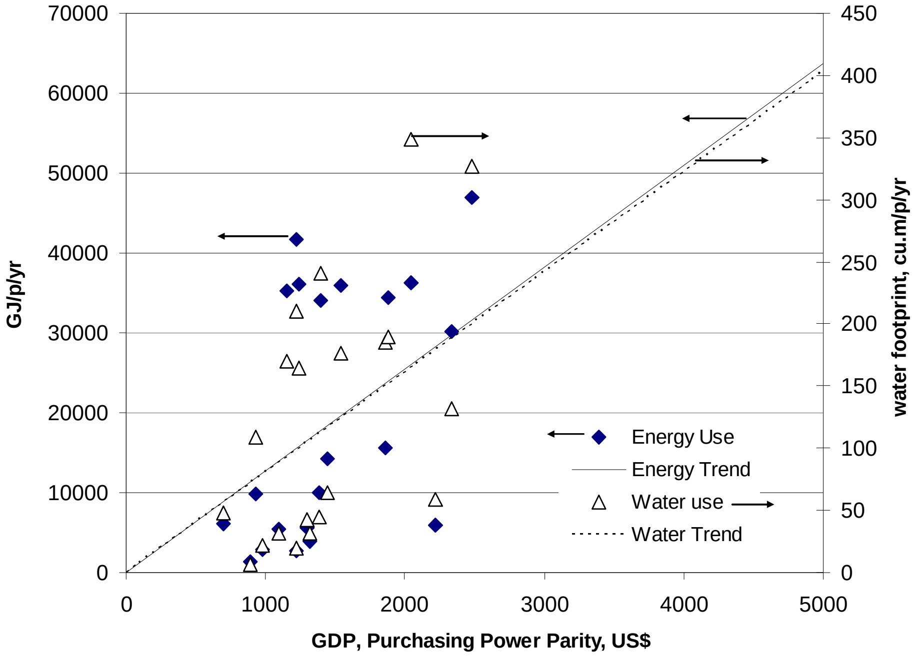

Fig. 2. Energy and water footprints of nations

2. Energy Sustainability

The discussion above on the unsustainability concerns about energy and the consequences of the transition from largely fossil-based to largely CO_2-neutral energy leads us to a definition of energy sustainability. It is however important to clearly tie any definition to a system. It is important because global energy sustainability has its context, potential solutions and the problems to overcome, which are different for that of a nation or a region within a nation.

– A "system" such as a country or a region can be said to have achieved energy sustainability if it has a secure supply of energy it needs, including importing from reliable sources, for the long term.

The system of interest, however, could be a particular solution or an energy system, in which case the definition would have to be somewhat different.

– An "energy system" can be said to be sustainable if it provides the societal benefit of power and fuels, is exploited profitably, and emits no net pollutions, including global warming gases such as carbon dioxide and methane, into air, water, and land resources.

In addition it may be necessary to define the corollary concept of energy security in the following way:

– A "system" is said to have achieved energy security if it is invulnerable to supply disruptions emanating from international price fluctuation, dwindling supplies, or terrorism.

It is obvious, however, that there is no energy sustainability without energy security.

Energy and water sustainability need to be analyzed in an analogous fashion. In each case there is a tendency to declare an energy extraction method more sustainable based on an insufficient number of metrics. If, for instance, just the greenhouse gas emission was the only metric one uses for biofuels compared with petroleum, the claim that biofuels are more sustainable would appear to be so. But, clearly many more metrics, economic, ecological and societal, should be used in making the comparison. In addition, the system definition is extremely important for making any meaningful assertion for the sustainability of energy. When energy sustainability of a country, such as the U.S.A., is being considered, a comparative analysis will involve an account of the current mix of energy sources vis a vis a future scenario that alters the mix to make the system more sustainable. Greenhouse gas emission is but one of the metrics to be used. An overall performance metric for U.S. energy situation will be energy consumption per unit GDP, compared with other countries, such as shown in Figure 3. Another metric would be GHG emission per million dollars of GDP (CO_2-equivalent) as shown in Figure 4. Clearly, both metrics tell us that overall U.S. economy is getting more efficient. But these two together cannot guarantee energy sustainability for the United States. Careful selection of metrics are needed to make a sustainability analysis, for which (i) either we are able to state that a future state, which is not just an incremental improvement, by the applicable metrics, are found to be more sustainable than the present situation, or (ii) we stay satisfied that since things are getting better, they will continue to get better. In the first case, we need to have a sense of certitude in our understanding of a more sustainable future state.

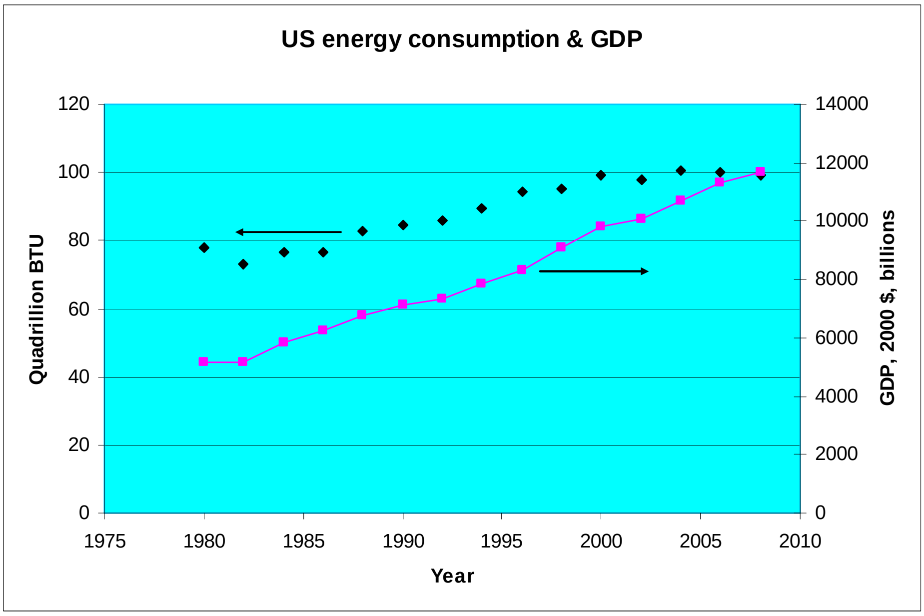

Fig. 2. *U.S. GDP has progressively getting more energy-efficient*

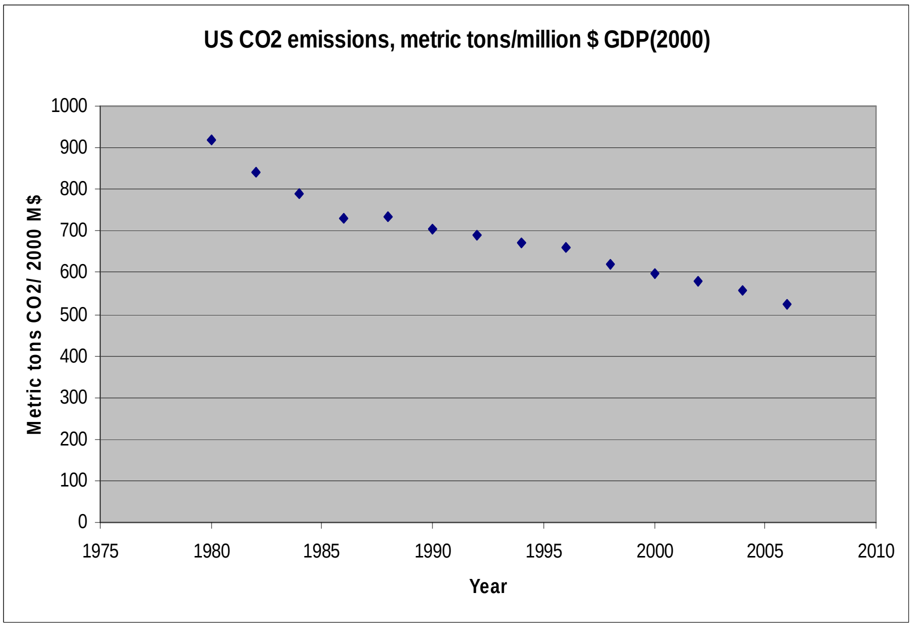

Fig. 3. *U.S. GDP is also becoming more GHG-efficient*

Tester et al. (2005) has provided a formalism for testing the sustainability of energy of a region by the following equation

$$S_e = [(P)x(GDP/P)x(E/GDP)] \sum_{i}^{n} w_i \quad [A_i\,(E)/E] \qquad (1)$$

where:

S_e – energy sustainability
$A_i(E)$ – i^{th} impact related to energy
w_i – weighting factor for the i^{th} impact
n – number of impacts
P – population

To compute a value for S_e one has to assemble a list of scientifically defensible metrics A_i representing economic, ecological and societal domains of energy development. S_e for a future state must be shown to be superior to current situation so as to be able to claim it to be more sustainable.

A somewhat different set of metrics would have to be used when we are evaluating an energy technology, such as a specific technology route for a biofuel such as ethanol. Here the frame of reference would have to be fossil fuel that this ethanol is supposed to partially or fully substitute. Equation 1 by Tester et al., as written above is inapplicable here, as we are no longer evaluating a regional system. However it seems that a similar approach could be taken without the first term before the summation sign. Currently there is no known satisfactory set of metrics one can use for energy technology systems.

Such metrics must be developed in order to do such an evaluation.

3. Water Sustainability

The assessment of water sustainability is currently evolving with several approaches being put forward recently. The challenges for these assessment methods are the translation of perceived abstract sustainability metrics to more practical and actionable outcomes, and the development of less qualitative and comparative methods, and more quantitative and site-specific assessment tools.

A review of water sustainability assessment approaches that are emerging reveals fairly simple to extremely complex methods driven by perspective, scale and location. The emergence of the "water footprint" concept by Hoekstra has led to the development of the first Water Footprint Manual (Hoekstra et al., 2009).

The water footprint is an indicator of both direct and indirect water use, with water sustainability increasing as the water footprint decreases. The water footprint of a product, consumer, producer, or place (i.e., community) shows water use and consumption by source and water pollution impacts, specified geographically and temporally. Hoekstras's water footprint is defined as the total direct and indirect use of blue water, green water and grey water.

- The blue water footprint is the consumption and loss of surface and groundwater from the available sources in a watershed or aquifer, including returning water to another watershed or aquifer or the incorporation of water into a product.
- The green water footprint is the consumption and loss of water that does not runoff into surface waters or infiltrate into the groundwater. It is the stored in the soil where it can be used by plants or lost through evapotranspiration. Agricultural production has a significant impact on the green water footprint.
- The grey water footprint is an indication of water pollution that represents the amount of water needed to make up for the pollutant loading in order to meet water quality standards.

The usefulness of a water footprint assessment relies on establishing goals and defining the scope. The goals and scope of a water footprint assessment connect perspective, scale and location to the purpose of the assessment. With the goals, boundaries and scope established, water footprint accounting is the next step.

The foundation of water footprint accounting is the water footprint of one process step. The summation of process step water footprints can lead to the water footprint of a product, for example. The water footprint of a person is the total of the product water footprints consumed or used by the person. Therefore, the water footprint of a community is the total water footprints of its members.

The water footprint for processes, producers, consumers and communities is expressed as a water volume per unit of time (i.e., gal/min). For a product, it is expressed as water volume per unit of product (i.e., gal/ton).

The usefulness of the water footprint as a measure of sustainability depends on the characteristics (size, timing, location, etc.) of the water footprint and the conditions in the place where the water footprint is calculated. As the size of the place where the water footprint is analyzed increases, the measureable impact of each water footprint is more difficult to identify.

Three recent efforts are presented here to illustrate the challenges of the application of water sustainability assessment to real-world challenges. These examples represent efforts by private industry and the public sector at various scales and attempts to more clearly functionalize sustainability assessments.

The Global Environmental Management Initiative (GEMI), a non-profit organization of leading companies has developed, "Connecting the Drops Toward Creative Water Strategies – A Water Sustainability Tool," (GEMI, 2002) which guides companies through a process to develop a business case for pursuing water sustainability.

In response to signs that companies should have more sustainable water strategies, GEMI's Water Sustainability Work Group developed a tool to meet both global and local water sustainability needs and to improve stockholder value and a company's competitive advantage.

The GEMI work group identified four strategic water trends that companies are seeing in industrialized as well as developing nations:

- Total water costs are increasing in many ways;
- Business risks are growing as current water allocations are not guaranteed into the future;
- Customer demands related to water use and impacts are changing; and
- The ability to operate and to expand is being tied to water-related performance, more often.

GEMI members and water experts recommend several options for managing water more sustainably, reducing risks, identifying opportunities and improving water security:

- For shared water resources, consider local human and ecosystem needs in business decision-making;
- Reduce overall water use;
- Match required water quality with appropriate use;
- Minimize adverse impacts on water quality and improve the quality of available water;
- Maximize the use of prevention and source control before treatment to meet water quality challenges;
- Engage local stakeholders about water management challenges; and
- Raise company awareness of water sustainability and effective stewardship.

The GEMI Water Sustainability Tool is made up of five major steps. The tool is a systematic process for companies to evaluate what the above listed trends mean for them. Each step, leads to a company-specific water strategy based on sustainability goals. Table 1 presents the Water Sustainability Tool steps, key questions and outputs that lead a company to a business-focused, sustainability action plan.

Table 1. Water Sustainability Tool Steps (GEMI, 2002)

Steps	Key Questions	Outputs
Water Use, Impact, and Source Assessment	In what key areas does the business directly and indirectly rely on and impact water throughout the value chain? What is the status or vulnerability of water sources used or impacted by the business?	Key Water Uses Key Water Impacts Key Water Sources
Business Risk Assessment	What are the business risks linked to the organization’s water uses and impacts, taking into account the vulnerability of key water sources affected by these uses and impacts? Which risks are most significant?	Prioritized Water Risks
Business Opportunity Assessment	What opportunities exist to proactively address costs and potential risks to the business associated with water use and impacts? What opportunities exist to create “top line” business value by addressing water challenges faced by others?	Opportunities
Strategic Direction and Goal Setting	What business case exists for pursuing a water sustainability strategy? What are the company’s goals related to water sustainability? How can the organization be best engaged in pursuing a water sustainability strategy?	Business Case for Action Water-Related Goals Strategic Direction
Strategy Development and Implementation	What roles should various business functions play in developing and implementing the company water strategy?	Key Organizational Roles Water Strategy and Action Plan

As companies move towards water sustainability, they will likely face resistance to change because of established practices, perceptions and policies. More sustainable water management may clash with corporate culture, public policy and market forces. But, delay will likely lead to missed opportunities for environmental improvement and market leadership.

In a recent report from the Electric Power Research Institute (EPRI, 2010), a new, more sustainable, water management paradigm was proposed. This paradigm is the outgrowth of an expert advisory panel meeting held in June, 2009. The panel examined two case studies (Tucson-Pima County, Arizona and Sanitation District #1, Kentucky) and formulated the key aspects of a new water management paradigm. The panel proposed that a new water management paradigm should be a composite of five integrated components: sustainability goals; sustainability operating principles; integrated technological architecture; institutional capacity; and adaptive management.

Focusing on the community level, the proposed EPRI water management paradigm places initial importance on establishing achievable, sustainability goals. To be of most value and usefulness to a community, goals should link directly to the desires and needs of community residents. In Sanitation District #1 (SD1), experience revealed that community members placed high value and interest on public health and the general well being of people; financial resources and the cost of delivering drinking water and wastewater services; dependability and reliability of water-related services; enjoyment and appreciation for parks and natural open spaces; and stewardship and conservation of our environment and natural resources for future generations. Based on these types of community values, a formal process can proceed to reach consensus on achievable sustainability goals to drive community, water-related decision-making.

The next component of the proposed EPRI water management paradigm is the adoption of sustainability operating principles. Combined with community sustainability goals, the following principles guide technological and institutional changes:

- Value the resource – water is a valuable resource and recognizing the value of the water cycle, as a system, is critical.
- Aspire to higher objectives that create better outcomes – water infrastructure designs should provide multiple benefits, such as the use of natural systems that can provide recreational opportunities.
- Consider context at multiple scales – most actions have effects at local, watershed, regional

and global scales and true sustainable decisions take these effects into account.

- Build intelligent infrastructure – communities should support the use of innovation and new ideas, including the use of monitoring and modeling systems.
- Integrate water management decisions with all aspects of community planning and development – all community decision-making must consider the impacts on water and the water cycle, especially those relating to land use planning and management.
- Share responsibility and risk throughout the community – by engaging all stakeholders from the beginning, greater ownership of the outcomes and acceptance of the risk can be achieved.
- Recognize the true costs of providing water-related services and maximize the value and benefits – full, life-cycle costs over a long-range (i.e., 100 years) are used to help make water management decision-making.
- Choose smart, clean and green – water infrastructure uses real-time data and information for management and control; avoids the use of harmful materials and substances; and learns from and works with natural systems to manage water and co-exist with the water cycle.
- Adapt and evolve – achievement of sustainability goals will be realized when flexible and adaptive systems are allowed to evolve over time based on continuous feed back and assessment.

Following sustainability goals and operating principles, the next component of the new water management paradigm is the movement towards more integrated technological infrastructure designs. Infrastructure systems must increase their efficient use, recovery and recycling of resources by recognizing that water itself is a resource and that energy and waste-related resources (biosolids and nutrients) can be recovered and recycled. Water infrastructure should reflect an efficient balance of scales, utilizing centralized and decentralized systems to manage resources closer to where they are generated, used and reused. Water infrastructure systems should provide multiple benefits, that achieve the environmental, societal and economic goals. Lastly, new water system designs should be, to the extent possible, based on natural systems and work within nature.

The next component of the new water management paradigm is building institutional capacity to support sustainable operations and following the sustainable principles listed above. Communities can focus on a broad range of areas as they build their institutional capacity to help reach their sustainability goals, including integrated community planning focused on smart growth and watershed management; full life-cycle costing; revised and new regulations based on sustainability principles; active and continuous community engagement; investment in intellectual capital; and the use of market mechanisms.

The final component of the new water management paradigm is adaptive management. This component recognizes that progress towards the achievement of a community's sustainability goals is likely to be incremental. When water management performance assessments reveal unacceptable outcomes, adjustments to goals, policies, methods or operations will be needed. Acceptance of this reality, along with developing monitoring systems to measure progress, permit communities to adapt without viewing shortfalls as failures.

At the Water Environment Federation (WEF), Technical Practice Updates (TPU) are published to provide a summary of the state of the knowledge regarding the practical implications of an emerging issue. In September, 2009, WEF published a TPU summarizing the evolving methodology for rating watershed sustainability (WEF, 2009). This TPU proposes a watershed methodology that builds and expands on existing elements currently used to assess watershed sustainability, including human use of physical characteristics, water and wastewater treatment facilities, and significant industrial facilities. At this point in time, this methodology does not consider land use within the watershed. It is expected that as this methodology evolves, the impact of land use on watershed sustainability will be included.

WEF goes further to propose that it may be possible to certify a watershed as sustainable. While the methodology shows how steps could be taken in that direction, WEF does not try to answer the question of how this would be accomplished. This methodology is an initial step to suggest how a foundation for a certification process could be established.

The proposed watershed sustainability rating methodology includes four areas for evaluation: human use of physical watershed characteristics, municipal drinking water systems, municipal wastewater systems, and major industries. These component ratings are then combined in some manner to produce an overall sustainability rating for the watershed. Each component rating is based on established evaluation approaches.

The first component rating relates to human use of the physical characteristics of the watershed. Ratings from 1 to 5 (least to most sustainable) are provided by watershed stakeholders for each of the following seven characteristics: surface water, flood plains, marshes, aquifers, topographic and geologic features, forests and woodlands, and prime agricultural land. (McHarg, 1969) The overall rating is the arithmetic average of these seven ratings. The rating process includes the use of quantitative measures and professional judgment about each characteristic.

It is proposed that a possible rating process for drinking water systems be based on a framework developed by the Water Research Foundation (formerly the American Water Works Association Research Foundation) and the Commonwealth Scientific and Industrial Research Organization of Australia called "Triple Bottom Line Reporting of Sustainable Water Utility Performance." (WRF, 2007) This framework includes objectives and assessment criteria based on sustainability principles for a water utility and measurable indicators for each criterion. While a rating system is not yet proposed, it could be based on the approach for wastewater systems, described below.

For each wastewater system to be rated in a watershed, it is proposed that an approach described in "A Sustainability Rating Tool for Wastewater Systems" (Mosley, 2006) be applied. A very detailed assessment of each wastewater system in a watershed is proposed using a 71 point scale. Three major assessment categories are provided to develop a composite sustainability score for each system: general, including innovation; planning, design, construction and startup; and operations. An average of all wastewater systems in the watershed is applied to the watershed. In this approach, an alternative could be to calculate the overall watershed value based on a flow-weighted average, given more influence to those wastewater systems with the highest system flow rates.

The final component rating is a modification of GEMI's "Collecting the Drops: A Water Sustainability Planner." (GEMI, 2007) This process assesses a broad range of areas for major industrial facilities that use large amounts of water. Each facility in a watershed is rated for risk using a 5-point scale for numerous factors relating to watershed, water supply reliability, efficiency, water supply economics, regulatory compliance, and societal considerations. In this component rating, the lower the risk, the higher the sustainability.

The proposed WEF rating for overall watershed sustainability would be some type of combination of the four rating approaches discussed above. One suggested approach is to establish ranges of scores that differentiate between sustainability in the low, medium and high ranges. Although rather simplistic, this approach enables comparison of watersheds which can help stakeholders set goals and priorities for improving the sustainability of local watersheds.

4. Sustainability Metrics Aggregation

We have seen how, at least in principle, the aggregate sustainability of energy systems can be determined by the use of Equation 1. Similarly, an aggregate sustainability measure for water systems can be fashioned after Tester et al.(2005)

$$S_w = [(P)x(GDP/P)x(W/GDP)] \sum_i^n w_i \; [A_i(W)/W] \qquad (2)$$

where:

$Ai(W)$ – i^{th} impact related to water
wi – weighting factor for the i^{th} impact
n – number of impacts
P – population
W – total water use

Of course the value for $S_{w,}$ just as in the case of energy, does not provide any sense of sustainability, unless this value is compared with another "state" of the same system with different impact values and/or weighting factors.

Equation (1) and (2) are applicable to community or regional systems with population and GDP as important parameters. For energy- or water technology systems, however, the first term in the equations could be dropped and only the impacts (i.e. economic, environmental and societal) of the technology system are computed to yield values of S_e and S_w. As argued in a recent paper (Sikdar, 2009), since the various impacts will have different units of measure, the use of the additive term would prove to be difficult to defend in these equations. An alternative that allows direct comparison uses the geometric mean of the ratios of the same impacts at two different states of the system. Thus the corresponding equations for energy and water sustainability, respectively, can be expressed in the following way:

For regional energy system:

$$D_e = S_{e,\, state\ 2}/\, S_{e,\, state1} = \Big(\prod_i^n w_i \; [\{A_{i,2}\,(E)/A_{i,1}(E)\}]\Big)^{1/n} \qquad (3)$$

and for the regional water system:

$$D_w = S_{w,\, state\ 2}/\, S_{w,\, state1} = \Big(\prod_i^n w_i \; [\{A_{i,2}\,(W)/A_{i,1}(W)\}]\Big)^{1/n} \qquad (4)$$

where the metrics D for energy and water represent a comparative measure of sustainability. Typically, a value of greater than 1 would be worse or less sustainable for state 2, less than one, better or more sustainable.

Note that the first term involving population and GDP drop out of both equations. It is understood that the values of A_i 's are normalized either by P or by GDP (i.e. impacts per capita or per unit of GDP). Moreover, the same equations now are applicable to energy and water technology systems as well.

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Energijos ir vandens sistemos: ką reiškia jų darnumas ir kaip žinoti, kada jis pasiektas

Subhas K. Sikdar, Daniel J. Murray

Nacionalinė rizikos valdymo tyrimų laboratorija, JAV Aplinkos apsaugos agentūra

(gauta 2010 m. balandžio mėn.; atiduota spaudai 2010 m. birželio mėn.)

Terminas „darnumas" taikomas įvairiose srityse: kalbant apie gamtinius išteklius – energiją, vandenį; gaminius, procesus, miesto infrastruktūrą (pvz., miestus); arba apie tariamai natūralią infrastruktūrą – ekosistemą. Atlikta nemažai tyrimų vertinant gaminių ir procesų darnumo lygį pagal ekonominius, aplinkosauginius ir socialinius veiksnius, tačiau tokios sisteminės analizės neatliekamos vandens ir energijos kaip išteklių arba vandens ir energijos tiekimo sistemų darnumo lygiui nustatyti. Straipsnyje aptariami vandens ir energijos tiekimo sistemų darnumo aspektai, pateikiant tam tikrų idėjų apie darnumo lygio ir galimų pagerinimų vertinimą.

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