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EDITORIAL

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Why should I?

Early in February 2007, I chaired a breakout session during a conference organized by the National Council for Science and the Environment. The titular focus of that conference was "Integrating Environment and Human Health," an issue embedded deeply in wider sustainability goals. The more specific aim of the breakout session was how to design for complementarity among programs that are generating an unprecedented amount of health- and environment-related research information and data to facilitate easier use and greater effectiveness in assessment and stakeholder-decision processes. Significantly, the session's focus was central as well to the challenge, and objectives, of establishing desirable outcomes from actions and programs initiated to address the intersecting issues that characterize sustainability science, practice, and performance.

The session attracted a rich spectrum of disciplinary specialists. It was structured with an understanding among participants that the expertise needed to explore the issue area was, indeed, "around-the-table." The participants were self-selected and they recognized the high value of capitalizing on what other disciplines could offer to the planning, conduct, interpretation, and reporting of their own work. Nevertheless, the researchers reported that they continue to experience routinely significant problems in implementing interdisciplinary cooperation. The first order of business articulated actual obstacles participants had encountered in getting research programs to complement and strengthen each other. Challenges ranged from the absence of a *lingua franca;* to organizational, regulatory, and ethical barriers; to finding, and effectively targeting funding toward, engaged collaborators. The discussion then moved to identifying priorities for action and targeting such issues as the need to understand and value interdisciplinary complexity; the culture of science and technology practice; and the structural barriers to standardizing data acquisition and management and, importantly, the sharing of that data. With challenges and priorities laid bare, the group moved on to articulate recommendations that it would make to such likely and traditional gatekeepers as professional societies, funding agencies and foundations, the private sector's research and development establishment, and domestic and international academe.

The group's recommendations echoed many study reports on linking disciplines. If we consider only the past 30 years, there is a substantial extant resource of inquiry on the nature and promise of integrative research. These resources are chronicled in government, academic, foundation and private sector, and professional society studies, as well as in findings reported in scholarly journals and popular commentaries. One of the most recent, compelling, and thorough of these assessments, *Facilitating Interdisciplinary Research*, represents an addition to a group of keystone reports carried out by the Committee on Science, Engineering, and Public Policy (2004) of the National Academies. These studies prompted the establishment of, and continue to guide, the Keck Futures Initiative that aims to bolster more comprehensive realization of interdisciplinary research. Even commentators such as Tapscott & Williams (2007)—reporting in a popular, albeit highly business-oriented, venue—identify and expound upon what they call "a deep transformation in science and invention." This article hones in on the need to move forward through open-source approaches, and through the collaborative advantages afforded by information technologies, to the integration of all sciences.

In light of this landscape of reports and recommendations, I suggest that rather than tilting at often nebulous organizational, institutional, and cultural barriers—or against such support mechanisms as the lapsed Research Applied to National Needs Program or the existing Integrative Graduate Education and Research Traineeship Program—a more direct, palpable, and personal response is needed. Very much in the mold of the studies, initiatives, and commentaries mentioned earlier, the recommendations of the breakout session overlooked what I believe to be the most fundamental constraining factor in the quest for interdisciplinarity. That is, participants in this discussion neither identified nor explored the *human dimension.* None of the efforts targeted squarely the behavior of the individual (read individual scientist). Obviously, I feel that to make interdisciplinarity—and subsequently, complementarity—a reality among often-isolated disciplines, the mindset of individual scientists must shift. Scientists must believe that, through their own dedicated action, interdisciplinarity *can* be achieved; and those individuals *must* be willing participants in making it so. They must recognize that it is the end goal that matters, that end goal being more comprehensive research, understanding, and knowledge.

We recognize that at times scientists have been known, in the competitive world that is science, not to share the limelight. Also, at the outset, I must say that I do think that sustainability scientists by necessity have come a very long way in overcoming this learned, constraining attribute. This posture is due to their widening recognition of the bewildering array of disciplines now working separately on topics relating directly to the maintenance and improvement of the condition of our health, the health of ecological systems and their resident biota, and our economic and social systems. Nonetheless, more must be done to demonstrate to a larger universe of science practitioners the inherent value in taking bold decisions about—and making decisive steps toward—interaction. There is a critical need to *exercise* the mindsets of individuals doing science regarding what is most valuable to the trajectory of—and satisfaction with—their careers.

We know that many scientists find their sense of reward and recognition controlled, as yet, by outside institutional and cultural forces. How, then, do we get established, as well as new and budding, scientists to adopt cooperative and integrative ways? My suggestion is to reopen the discussion on what a scientist is. Back in 1989, the National Academy of Sciences produced a seminal volume entitled *On Being a Scientist*. Six years later, an updated version was issued in which the authors reiterated their vision of the "ethical foundations of scientific practices and some of the personal and professional issues that researchers encounter in their work" (Committee on Science, Engineering, and Public Policy, 1995). Rethinking the relevance of this important document is warranted in light of growing realization of the substantial benefits of integrating research and the still evolving issues surrounding the right to hold on to data and information (intellectual property)—data and information that in many cases may be, in fact, public property. Just as the second edition of this report was undertaken to explore scientific practices related to both individual and institutional conduct that were seen to violate the ethics of science, a further revisiting could focus on issues, questions, and opportunities posed by the increasing need for interaction across the spectrum of scientific disciplines.

Furthermore, I believe that given their head start in being necessarily embedded in complementary studies that cross disciplines, sustainability scientists can, by example, enhance the relevance of their work to that of other disciplines. They can be in the vanguard to address the human dimension by pointing to ways for individual scientists to make their work more comprehensive, more defensible, and likely more credible. Coupled with a second updating of *On Being a Scientist*, we can help the individual scientist to shift into a mindset that turns the question "*Why Should I*?" into the clear-cut declaration "*Why I Must.*"

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ARTICLE

Ambition and reality in modeling: a case study on public planning for regional sustainability

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A comprehensive systems approach is a prerequisite for the development of sustainability policy strategies. Quantitative models are frequently proposed as useful building blocks in this regard. We examine the value of such models in a case study on regional sustainability carried out in cooperation with the administration of the Dutch province of Limburg. With the participation of an interdisciplinary group of civil servants, we developed an influence diagram representing the region and compared this to the coverage of quantitative models used in provincial strategic planning. The significant discrepancies between the two types of system representation lead to a more diligent interpretation of results, help to improve the models, and set challenges for future model use in regional sustainability planning. This article provides policy makers with practical advice on strategic planning and encourages scientists to improve the models by developing new techniques for the integration of quantitative and qualitative analyses.

KEYWORDS*:* regional planning, sustainable development, prediction models, systems analysis

Introduction

Regional administrations aiming for sustainability face complex issues resulting from interactions, feedbacks, and trade-offs among various aspects of sustainability, as well as from dynamic structural change. The normative character of sustainability further enhances this systemic complexity—individual and social preferences differ and evolve over time. The difficulties of trying to manage, control, or manipulate such complex systems, even with the best of intentions, have been well documented (see, e.g., Forrester, 1971a; Sterman, 1994; Meadows, 1999; Sterman & Booth Sweeney, 2002; Dörner, 2003). It is widely agreed that addressing these characteristics requires a comprehensive systems approach (see, e.g., Schellnhuber & Wenzel, 1998; Ehrenfeld, 2005).

The exact definition of a systems approach is as elusive as that of sustainability, but researchers propose quantitative models as at least one building block of such an approach (Rotmans, 1998; Robinson, 2004). However, there are significant discrepancies between the ambitions and the practical reality of such models. According to van der Sluijs (1997), the ambition is to

> model the complete so-called causal chain, including all the feedbacks within this chain. The causal chain starts with socio-economic drivers leading to economic activity and other practices, leading to emissions and other pressure on the environment[,] leading to environmental changes, leading to physical impacts on societies and ecosystems, leading to socio-economic impacts, eventually returning to cause changes in the socio-economic drivers.

Other ambitions include the transparency of models; their capability to explore uncertainties, trend breaks, and discontinuities; their potential to foster deliberation; and their relevance to decision makers. We are currently far from meeting these objectives. In an overview of challenges for Integrated Environmental Assessment, Toth (2003) reflects on models referring to sustainability. He concludes that, despite significant progress in recent years, the available models are not suited for addressing the complex problems on current policy agendas. Progress on this front will require innovative integration techniques.

We come to a similar conclusion after assessing 13 European and global integrated scenario models, including a set of integrated models regarding sustainability (Greeuw et al. 2000). In particular, the evaluated models do not fulfill the objectives of horizontal and vertical integration and policy relevance. Horizontal integration refers to the amalgamation of different aspects of a model's domain. Issues of assimilation between the environmental, economic, and sociocultural domains, as well as integration within each of these domains, are important in this respect.

Vertical integration refers to the incorporation of different stages of cause-effect chains in the sense of the pressure-state-response cycle (OECD, 1993). Greeuw et al. (2000) also identify a significant neglect of sustainability's sociocultural domain. The indicators chosen to represent this domain are largely demographic or economic, and only marginally correlated to the underlying system. The assessment further reveals a trade-off between horizontal and vertical integration. While the sociocultural domain is not explored in satisfying depth, the economic domain seems to privilege depth over breadth.

A case study commissioned by the administration of the Dutch province of Limburg allowed us to study in detail the discrepancies between ambition and reality in models for public strategic planning and regional sustainability. The next section introduces the project. We subsequently describe the methods and result of drafting a conceptual integrated system representation of the province in a participatory process. This qualitative approach is followed by an inventory of quantitative forecasting models used by the provincial administration to support its strategic planning. The differences between the relationships covered in the conceptual representation and in the structure of the forecasting models are analyzed. In the concluding section, we offer some practical advice on how to better use existing models and on how to bridge their discrepancies.

Project Overview

In regional strategic planning, forecasting and exploratory studies are crucial. Integrated and forward-looking research supports the planning process by structuring relevant discussions and by facilitating the development of robust strategies. In the Netherlands, legal mandates require that these studies be conducted at regular intervals for some sectors. The Dutch province of Limburg was the first of the country's twelve provinces to combine its sector plans into a single, integrated strategic plan: the *Provinciaal Omgevingsplan Limburg*, or POL (Provincie Limburg, 2001). To better harmonize the underlying forecasting models, the provincial government commissioned a year-long participatory project.

For purposes of this article, two of the four project phases are of particular interest. One phase was devoted to the participatory drafting of an influence diagram representing the dynamics of regional development in the province. The other phase was predicated upon an inventory and evaluation of the quantitative indicators and forecasting models used by the provincial administration for strategic planning. Six senior civil servants with different backgrounds formed the core group for the participatory process. Especially early in this process, additional members joined this group to provide specific practical expertise, to increase internal transparency, and to satisfy general interest. During the year, the group worked with our team during 17 workshop sessions of approximately three hours each.[1]

Influence Diagram

To facilitate horizontal integration in the administration and among the different forecasting models, we dedicated the first phase of the project to the participatory development of a conceptual integrated system representation of the province. The purpose of this process was to strengthen mutual understanding, to sharpen awareness for the interdependencies between different characteristics and regional developments, and to structure the available information and knowledge in an integrated manner.

We drafted the conceptual integrated system using the SCENE approach (Grosskurth & Rotmans, 2005). The acronym SCENE stands for the three domains of sustainability: SoCial, ENvironmental, and Economic. This approach was developed to foster a better understanding of sustainability's underlying dynamics and of related issues. SCENE is based on the participative and qualitative representation of stocks and flows in the format of an influence diagram. The three domains of sustainability provide the fundamental structure for SCENE. Stocks describe core elements of a system that change relatively slowly. In contrast to the system-dynamic notion given to the terms "stock" and "flow," SCENE stocks can be generic titles such as "lifestyle" or "economic vitality." Moreover, these titles can be interpreted multidimensionally. In the SCENE approach, we generally take four dimensions of a stock into account: quantity, quality, function, and spatial dimension. This methodology breaks with the legacy of system-dynamic modeling where only one dimension of a stock—mostly quantity—is generally taken into account. Flows are relationships between stocks. Flows can represent material flows, information flows, or other relations that follow a cause-effect line. The resultant description of the system is a conceptual model of the real world. During the past five years, we have drafted such models by applying the SCENE approach at national, provincial, and urban levels. Figure 1 is a schematic representation of the "naked" SCENE model.

With SCENE, the "sustainability triangle" is transformed from a concept for the structuring of sets

[1] Full documentation of the project, the influence diagram, a detailed explanation of each stock and flow, as well as the full inventory of models, is contained in the project documentation and available from the author (in Dutch).

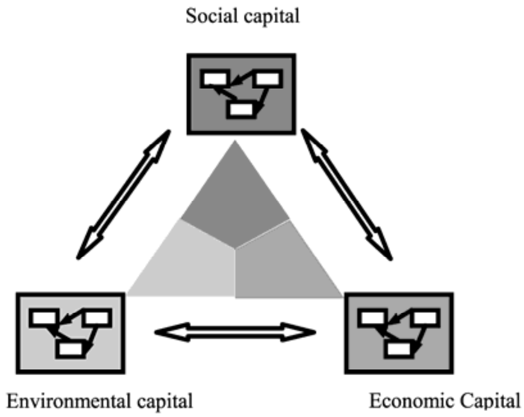

Figure 1 The conceptual structure of the SCENE model.

of sustainability indicators to a framework that allows for the representation of underlying dynamics. For an integrated description, it is crucial that all three capital domains are conceived at the same level of conceptual detail.

Drafting the influence diagram for the POL project was a two step process: 1) selecting and describing the stocks that comprehensively represent the province of Limburg and 2) mapping the influences between these stocks. The participants were advised to develop the diagram of the province in the present and to try not to anticipate possible future changes. The concept of sustainability was implicit in the process as the balanced development of the economic, sociocultural, and environmental domains.

During the first several sessions, the group proposed a set of issues and topics. In an interactive and iterative process of screening, revising, reformulating, and restructuring, this initial list was brought together into a set of 18 stocks that implicitly comprised all indicators regularly monitored by the administration. The stocks were compatible with other documents published by the Province, but covered a wider range. The structure and wording of the stocks corresponded to the administration's internal organization and communication habits.

The 18 stocks (and their labels) are: population (Popu), consumption (Cons), social structure (Soci), public amenities (Amnt), housing (Hous), security (Secu), space (Spac), air (Air), groundwater (G-wat), surface water (S-wat), soil (Soil), nature (Natu), entrepreneurship (Entr), production (Prod), knowledge and innovation (Know), work (Work), mobility (Mobi), and infrastructure (Infr). For each stock, the group formulated an abstract with a description of the stock, its characteristics, and its scope. For example, the characteristics of the stock "knowledge and innovation" include knowledge institutions, public and private research and development, applications of knowledge and innovation, as well as the spatial distribution of these factors.

The set was also screened for comprehensiveness based on Vester's (2002) system criteria. Vester is author of the Sensitivity Model Prof. Vester®, a computerized planning and mediation tool for complex systems. The software has frequently been applied in urban and regional planning where stakeholders describe their region as a system. These system representations form the basis for subsequent simulation and intervention steps. To check their comprehensiveness, Vester derived a set of criteria based on his experience and system understanding and meant to guarantee the balanced representation of all relevant aspects of the system. These system criteria require at least the implicit inclusion of seven specific areas of life (e.g., economy, population, and infrastructure), three physical categories (material, energy, and information), four dynamic categories (e.g., flow or time dynamic), and four system-relational categories (that open the system to outside influence or can be influenced from within). The 18 stocks selected satisfied the areas of life and the physical categories of Vester's criteria. The dynamic and system-relational categories were not satisfied at this stage as they can only be met after the relationships among the stocks have been represented.

To draft these relationships, the participants individually filled in an empty matrix with the 18 stocks as row and column titles. Each cell represented a potential unidirectional flow from one stock to another (though not to itself), resulting in 306 possible flows. Working independently, the participants marked the cells where they perceived a direct influence. They then added a strength estimate (weak, medium, or strong) and a short description of the influence they had in mind. We then combined the individual matrices into a single document, checked the results with experts and, in instances of doubt or dissent, presented it to the group. Among themselves, the participants noted their agreements, discussed and clarified their disagreements, and identified uncertainties. We added comments from the expert scan. These remarks were mostly concerned with additional information about previously identified relationships, thus enriching the group's discussions. In total, 95 flows were selected and documented—15 strong, 46 medium, and 34 weak. For example, both participants and experts agreed that the stocks "population," "public amenities," and "entrepreneurship" all influence the stock "knowledge and innovation." This latter stock, in turn, influences "entrepreneurship," "population" (both are bidirectional relationships), and "production." Figure 2 shows the complete influence diagram (without the flow strength). The stocks are coded by color and shape to make clear the distinction between stocks in the various domains: sociocultural (red circle), environmental (green box), and economic (blue diamond).

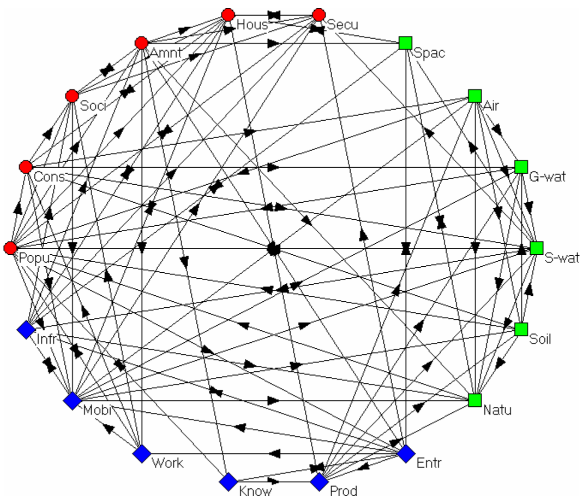

Figure 2 The conceptual SCENE model for the Province of Limburg.

Model Inventory

To compare the completed SCENE model with the coverage of the available quantitative models, we conducted an extensive inventory and represented the underlying structures in the same format as in the previous section. In total, we identified 13 quantitative models that the administration had previously used for strategic planning:

- The local research institute ETIL contributed separate models on three issues: population, labor markets, and housing. These models translate national forecasts on these issues down to the regional level using a shift-share approach (ETIL, 2000).
- The PRIMOS model produces forecasts on overall population size, number of households, and housing requirements. The acronym stands for *PRognose-, Informatie-, en MOnitoring Systeem* (Prognosis, Information, and Monitoring System) (ABFresearch, 2006a).
- The RDP model (a Dutch acronym for Spatial Demographic Forecasting model—*Regionaal Demografisch Prognosemodel*) produces region-specific population projections based on national estimates and is quite similar to the ETIL models, though the underlying assumptions differ (ABFresearch, 2006b).
- The *InterProvinciaal woningBehoefte-model* (IPB—Interprovincial Housing Needs Model) is a highly simplified shift-share module that produces population forecasts on the community level (ABFresearch, 2006c).
- The RAIL (*Regionale Arbeidsmarkt Informatie Limburg*—Regional Labor Market Information Limburg) model produces a regional sector-specific forecast on Labor Market supply and demand (Teunis, 1996).
- The COMBI *(een COMBInatie van modellen*—a COMBInation of models) model forecasts regional migration patterns for the country as a whole based on population, labor market, housing, and higher education modules (Heida & Poulus, 1993).
- The Dutch Central Planning Bureau (CPB) produces a set of three quantitative scenarios with respect to environmental quality, mobility, space, and energy. These scenarios are documented in CPB (1996).
- The OGM model (*Overdraagbaar Groeimodel*—Transposable Growth Model) forecasts developments in regional mobility (4cast, 2006).
- The MIOW-PROV model forecasts the socioeconomic consequences of environmental regulation. The acronym stands for *Marktsituatie, Internationale concurrentie, Omvang en Weerstandsvermogen PROVinciaal milieu-economisch model*—Market Position, International Competition, Volume, and Resilience Provincial Environmental-Economic Model (Woerd et al. 1997).
- PROVEST (*PROgnosemodel VESTigings-locaties*—Forecasting Model on Locations of Commercial Settlements) forecasts the physical space required for the development of business and industry in a shift-share manner (BCI, 1998).
- The *LeefOmgevings Verkenner* (LOV—Environment Explorer) is a geographic information system (GIS)-based model for exploring changes in land-use patterns. The evolving maps cover a large set of land-use types, and so include social aspects such as housing, environmental aspects such as open landscape, and economic aspects such as infrastructure (Engelen et al. 2003).

Overall, four models had a demographic focus, five had a socio-economic orientation, two pertained to the labor market, and two concentrated on land use. Some of these tools were simple shift-share models that translated national extrapolations down to the regional level, while others were sophisticated stand-alone constructions based on statistical regression, general equilibrium, or GIS approaches. Approximately half were developed specifically for the region and the other half are nationally run models that are disaggregated and optimized over all Dutch provinces. These two model types often cover similar topics.

Due to divergent assumptions, regional and national models are often at odds in their projections. The differences are a consequence of statistical estimation biases to which outliers in panel-data sets are subject. For example, labor is highly mobile between most Dutch provinces when one location has vacancies in employment and another has unemployment. However, this mobility does not extend to the peripheral provinces, including Limburg. As Limburg historically had many vacancies unfilled, the national forecasts assumed high immigration into the region and thus projected a higher population than region-specific models that neglected this relationship. In the past, the lower population forecasts have turned out to be the better estimates for Limburg.

As many of the evaluated models are either run at the national level or shared among the provinces, it is safe to assume that the set is representative for other provinces in the Netherlands. Members of the Limburg administration, who frequently took part in interprovincial meetings on monitoring and strategic planning, supported this view. At smaller-scale levels, the coverage of the models seems to get even thinner; at higher-scale levels, the coverage is slightly improved as more general and global models become relevant.

We translated each model into an influence diagram using the stocks described in the previous section. To accomplish this, we screened the available primary and secondary model documentation and conducted extensive interviews with the model developers and/or owners where documentation was insufficient. We accepted a flow as being covered by a model when its framework incorporated any aspect of the flow (either exogenously or endogenously). For example, the flow from "knowledge and innovation" to "entrepreneurship" is represented in the relevant models as an exogenous constant by which productivity increases each year. This facet of the model would obviously be insufficient to explore the effects of changes in the education system and it certainly does not answer potential questions of public officials about increasing entrepreneurship through stimulating knowledge and innovation. More generally, the description provided in the conceptual influence diagram is much richer than in the models themselves.

Figure 3 combines the separate influence diagrams for each model into a single overview.

Quantitative models used for strategic planning cover 30 of the 95 flows in the conceptual influence diagram. It is important that these modeled flows are not necessarily comprehensively addressed and the different models are not at all compatible in their underlying assumptions or the methods used to make the ultimate calculations. The models are certainly not calibrated for use within a single system of models. This fragmentation of coverage is lost in the illustration above.

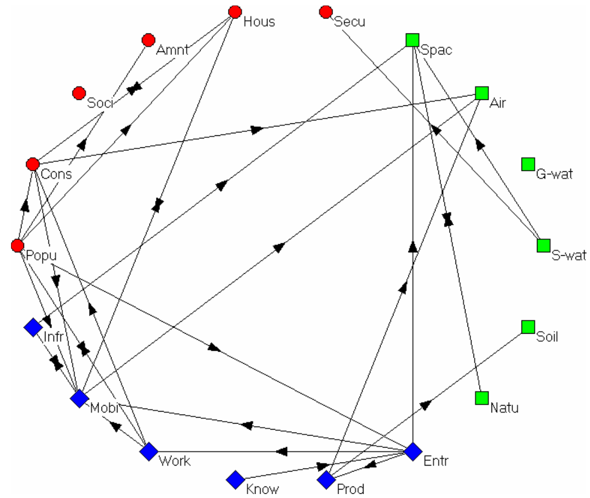

Figure 3 Flows covered by quantitative forecasting models.

The stocks "social structure" and "groundwater" are not covered at all. A third of the remaining stocks are only connected to the system via a single remaining flow. Some flows are covered by several models, most of which concern population and labor-market dynamics. We did not detect a single flow covered in any of the models that group participants had not previously identified. Well-covered stocks include the extent and condition of "housing," the effects (but not the causes) of changes in the "population," the economic effects of "entrepreneurship," changes in land use ("space"), and the situation regarding "mobility." Other economic—and most social and environmental—stocks are not covered at all or, at best, their treatment is highly superficial. A more favorable picture emerges when the weights of the flows are taken into account. There is coverage of 12 (out of 15) strong flows, 16 (out of 46) medium flows, and only two (out of 34) weak flows.

Discrepancies

It is immediately obvious that the loss of information moving from qualitative to quantitative analysis is dramatic. Figure 4 shows the 65 flows that are not covered in the models, but that were identified during the project's first phase. It shows the discrepancy between the ambition of van der Sluijs's ideal model (1997) and the reality of models that typically inform public strategic planning.

The discrepancies below the surface of Figure 4 are likely even more significant. While the models covered well the dynamics between the stocks labeled "population," "housing," "entrepreneurship," and "mobility," the majority of other flows were reduced to exogenous parameters. This observation

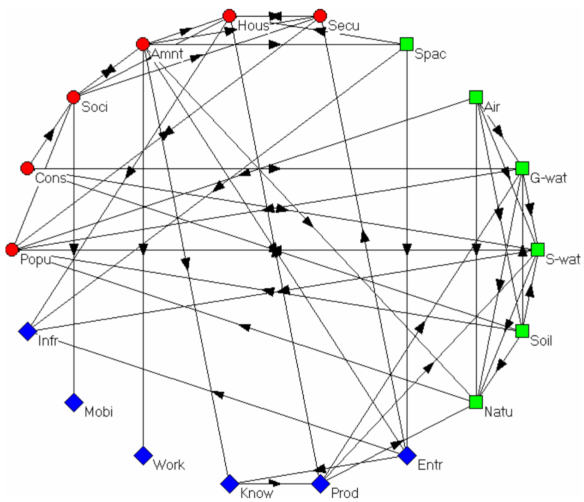

Figure 4 Flows not covered by quantitative forecasting models.

implies that the dynamics of the system rely fully either on a statistical analysis of the past or on a rough estimate of parameter value. In many cases, the exact parameter values were not documented. Inaccessible parameters mean that flows are putatively covered, but not documented in an accessible way. Because of this lack of transparency, even simple scenario studies cannot be executed in an informed manner. The richness of the qualitative influence diagram is almost completely lost.

Not surprisingly, there is a clear relationship between the ease with which a stock can be quantified and its inclusion in the models. We were able to deduce this straightforward relationship from the inventory of provincial indicators. On the one hand, "security" and "social structure" are lost from the inventory and from the models. Their core characteristics are "soft" and notoriously difficult to quantify. "Population," on the other hand, is a stock with very high data availability and, as such, is prevalent in the models.

We also witnessed a clear relationship between the coverage of different stocks and the modeling methods used to forecast them. More dynamic modeling techniques, such as general equilibrium of system dynamics, allow for scenario-type, longer-term explorations and often provide insights into counterintuitive developments (Forrester, 1971b). Integrated models of causal chains, as described above, require such dynamic techniques (Gilbert & Troitzsch, 1999). Parameter-based shift-share modules largely ignore these connections, give little insight into possible surprises, and only very rarely produce counterintuitive insights.

In our case, "population," "housing," "work," "entrepreneurship," and, to some extent, "mobility" were modeled dynamically and included a large number of feedbacks and interactions. General equilibrium modeling is the method of choice for the more sophisticated of these models. "Consumption" and "production," two stocks related to lifestyles and type of economic activity, are mostly covered as parameters in shift-share modules (e.g., translating economic activity into environmental impacts by assuming emissions per unit of production based on statistical analysis). All other stocks are covered in the form of calculated results of these simple shift-share procedures. This pattern is illustrated in Figure 5. A better integration of models would require coverage of a larger number of aspects using dynamic modeling techniques.

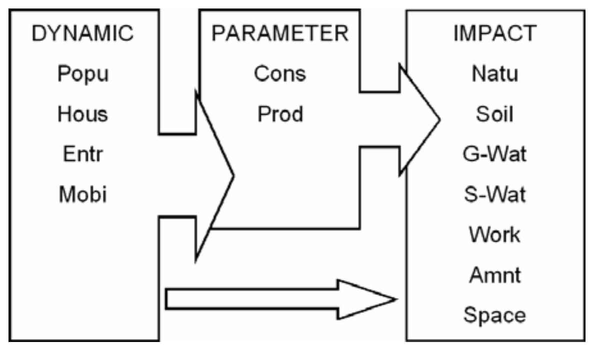

Figure 5 Stocks and modeling methods

One might respond by noting that the modelers apply Occam's razor quite skillfully. This principle requires that any explanation of a phenomenon should rely on as few assumptions as possible. The modelers minimize the number of assumed relationships by "shaving off" those with little statistical significance and thus reduce the system's complexity without significantly changing the dynamic properties. For the short run that might be true, but over the longer term, discontinuities in trends and other surprises are likely to result from causes located virtually anywhere in the system. Strategic planning must not, by definition, exclude these causes. Qualitative aspects of the stocks are not considered and influences currently deemed weak are omitted, severely limiting the models' adequacy for exploring the consequences of novel events and developments. Occam's razor is not compatible with rich, exploratory, forward-looking studies.

However, the fact that flows with high strength estimates are generally incorporated into the models indicates that the modelers are judicious in their application of Occam's razor. For pragmatic business-as-usual scenarios they do appear to set the right priorities. Just as the participants tended to give a higher strength estimate to flows subject to little uncertainty, volatility, and discussion, modelers focus on easy-to-measure and relatively stable flows. Yet, in E. F. Schumacher‘s classic phrasing (1977), “one restriction entails another. We attain objectivity, but we fail to attain knowledge of the object as a whole.”

Practical Advice on Better Use of the Models

Based on our analysis of the conceptual SCENE model and the corresponding model inventory, we formulated three recommendations for the provincial administration on how to better use its available models and how to efficiently improve the overall set.

First, a better understanding of the structure of the models is imperative for better use of their results. Our primary advice was to require disclosure of the parameter values whenever a model was commissioned. This small amount of extra insight would enable public officials to place a particular model in its proper context and to improve interpretation of its output in terms of validity and robustness. Also, simple scenario exercises that introduced different change rates—or even discontinuities—into the development of the parameters over time would create opportunities for transparency. Different futures can thus be explored in a rule-of-thumb manner. The results could also illustrate narrative scenarios of various futures.

Second, extension of the individual models would be an inefficient way to improve the integrated dynamics of the whole set. Harmonization of the underlying assumptions (and thus the possibility to vary them with full intention) would be a much more important step.

Finally, a fully functional integrated model with a sufficient level of detail is indeed possible. A model of this kind would, however, require considerable resources to implement while its comparability with the model runs of other provinces would be lost.

Bridging the Discrepancies

The first step in bridging the discrepancies between qualitative and quantitative analyses of complex systems must be a better understanding of the potential and the limits of both approaches.

Quantitative models have often been critically appraised. Godet (1983) criticized dependency on inaccurate data, coupled with unstable models and the explanation of the future in terms of the past, as an inherent property of statistical models. In response, he called for a global, qualitative approach.

The ensuing two decades have seen no fundamental progress in this respect. “Mathematical modelling is only possible if one is willing to except important parts of the problem and to limit an originally comprehensive understanding of the problem to the computable part of the problem” (Weimer-Jehle, 2006). Also, uncertainties are notoriously difficult to represent in quantitative studies that suggest precision and objectivity (Jaeger et al. 1998; 2001). Modeling results have little value once deprived of their underlying assumptions and context.

However, we found that the insights gained by provincial administration officials during the project helped them to make more appropriate use of the model results. An understanding of which factors were accounted for in the different studies, as well as an appreciation of the implications of different methods, helped the participants to use model results as arguments rather than indisputable facts. This experience confirms observations in similar projects. In reflecting on the ULYSSES project on urban lifestyles and sustainability, De Marchi et al. (1998) describe indications of mutual learning where the participatory processes included a somewhat odd “Mr. Computer.” The perception of the computer as a group member indicates the experience of mutual learning among human participants, the computer (model) and the modelers. Siebenhüner & Barth (2005) evaluate three major integrated assessment projects that embedded models in their participatory approaches: the ULYSSES project described above, the COOL project (focused on long-term climate options), and the VISIONS project (focused on developing integrated visions for a sustainable Europe). Even though these processes were mainly concerned with learning from models rather than about models, the authors indicate that some models “served as a trigger for debates about the implied uncertainties.”

A qualitative influence matrix also has limited value as a stand-alone product. Experiments on learning about dynamic systems have shown quite impressively that people have great difficulties conceptually learning about dynamic behavior, even under the most favorable circumstances (Sterman, 1994; Booth Sweeney & Sterman, 2001; Sterman & Booth Sweeney, 2002). Thus, the analytical power of quantitative models is currently the only technique available to structurally explore complex long-term dynamics (though not all modeling techniques are suited for this).

However, even without an exact understanding of the dynamics, mapping the province in the form of an influence diagram facilitated horizontal integration in organizational decision making. Civil servants from different provincial departments are now more likely to contact colleagues from other administrative units when their decisions might generate ripple effects and their mutual comprehension has improved. Vester (2002) provides anecdotal evidence of similar effects for a series of case studies: a working group on systems thinking set up in Bad Aibling (which continued to be active after his intervention), an altered structure for a regional planning group in Frankfurt, more integrated project perceptions at NERIS (*Netzwerk in der Risiko-Sensitivitätsanalyse*—Network in Risk and Sensitivity Analysis). Unfortunately, empirical studies on the effects of participation, the drafting of system diagrams, and the implications of learning about factual information—including model structures—are few and far between and quality criteria for participatory processes are disputed and generally hard to test (van de Kerkhof, 2004).

The direct path towards more comprehensive coverage in the sense of the cause-effect cycle described above would be to extend existing models to capture a larger number of dynamics. Such an effort would shift some stocks in Figure 4 from the right side to the left side, from impact and parameter status toward becoming integrated elements of the dynamic model. However, in many cases this would be mere window dressing as these models have been developed with a more focused target in mind. Toth (2003) warns modelers that they "should not extend their tools far beyond their original objectives because this might jeopardize the internal consistency and integrity of the [model]." Every flow added to a model exponentially multiplies the number of indirect influences and feedback cycles. This increase in complexity limits the dynamics that can be modeled without losing an overall understanding of the system's behavior.

Many model extensions would also require more data. The most far-reaching project in this respect is probably the Sustainability Geoscope that attempts to be an observation instrument for the anthropocene, the era in which natural and human dimensions of the earth system have become inseparable (see http://www.sustainability-geoscope.net). But it remains to be seen whether these additional data are actually useful for modeling purposes when there are breaks in the trends and the meaning of indicators changes. Bossel (1999) illustrates this effectively when he observes:

> As systems change and develop in a changing environment, individual indicators may lose their relevance and may have to be replaced by others that are more relevant under current conditions. Where once coal consumption per capita may have been a useful indicator of living standard, the number of computer chips in use per person may be a better indicator at another time.

Time-series analysis obviously becomes problematic under such circumstances.

The most ambitious option is to develop better ways to integrate qualitative and quantitative analyses. Such methods would combine some of the rigor of quantitative analysis with some of the richness of qualitative analysis. Numerous scholars have been calling for years for the development of such tools and some notable progress to that end is now being made (Rotmans, 1998; Kates et al. 2001; Toth, 2003; Robinson, 2004). A good example is the Georgia Basin project described in Tansey et al. (2002). The research team applied user-friendly model-based tools in participatory processes, triggering the participants to test the consistency of their narratives of a desirable future, to explore their choices and the consequences that followed, and to experience the resultant trade-offs. In addition to combining quantitative and qualitative exploratory methods, the exercise incorporated a strong element of learning.

Conclusion

We have observed a significant loss of information, combined with a gain in analytical possibilities, when moving from qualitative analysis to quantitative modeling. We have presented some indications that this result is transferable to other regions and other scale levels. Whether the loss of information outweighs the gain in analytical possibilities must be determined for each case individually. We have the choice between knowing a little of the whole or a whole lot of a little. Combining both approaches will remain a challenge for the future. Experiments to resolve these problems are being conducted. Models are increasingly open to "soft" factors, while qualitative scientists are strengthening the analytical aspect of their methods. It remains to be seen how fast the field will progress from clumsy first steps to a brisk walk. To advance along this path, current modeling tools appear unsuitable. A change is needed in the research paradigms of both modelers and qualitative scientists. Neither methodological approach can be expected to meet the other party on its own terms. Policymakers are caught between the two as numbers provide them with authority and suggest objectivity while narratives and the simplification of complex issues down to strong statements are the daily bread of politics.

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ARTICLE

User satisfaction and sustainability of drinking water schemes in rural communities of Nepal

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Water-supply programs consist of three essential components: technology, people, and institutions. The interface of these facets determines whether a particular scheme is sustainable. This article highlights the differences in maintaining and operating water-supply systems in rural villages and rural market centers in Nepal. The analysis considers disparities between users' willingness to pay based on data collected through surveys of 205 households and representatives of 12 water-user committees. Due to varying geographical locations and socioeconomic conditions among rural villages and rural market centers, core operation and maintenance problems for drinking water sustainability are immensely different. Weak institutional capacity is the prime obstacle in the provision of drinking water in the rural villages while technicalities such as insufficient water quality and inconvenient water-point locations are the major issues in the rural market centers. Moreover, levels of user satisfaction influence the operation and maintenance of both types of systems. This study considers user-satisfaction parameters and the overall influence of satisfaction on users' willingness to pay.

KEYWORDS: rural areas, municipal water supplies, sustainable development, social behavior, socioeconomic factors, drinking water

Introduction

Water supplies and sanitation were first highlighted on the development agenda about 30 years ago. This was a result of the 1977 United Nations Conference in Mar del Plata, Argentina that recommended proclaiming the 1980s to be the International Drinking Water Supply and Sanitation Decade with the goal of "provid[ing] every person with access to water of safe quality and adequate quantity, along with basic sanitary facilities, by 1990" (World Water Assessment Programme, 2003). International water policies and management practices have generally considered water to be a free and renewable resource. Governments in developing countries have often subsidized water supplies, typically in an attempt to achieve social and health benefits for low-income households that comprise a large majority of the rural population (Lammerink, 1998; Whittington et al. 1998). Furthermore, developing countries have made huge investments in their rural water supplies under the presumption that local communities will be involved in their maintenance and operation.

Rural water-supply schemes in Nepal are partially or fully funded from governmental and nongovernmental resources. Many governmental organizations (GOs), nongovernmental organizations (NGOs), and international nongovernmental organizations (INGOs) are working in Nepal to increase coverage and to provide safe water supplies and sanitation to underserved populations in poor and remote areas. The consumption of water in rural communities of Nepal is quite different from other countries. The customary strategy does not normally entail charging for water from public taps that are located among 5–15 houses within a 500 meter distance. However, other countries and agencies such as the World Bank recommend that users should pay for water services (Asthana, 1997). To escape problems created by this approach, donor and government officials in developing countries have focused on financial issues, especially the generation of revenue through domestic connection (Singh et al. 1993).

Project-evaluation reports from developing countries indicate that shoddy construction of drinking water supply (DWS) schemes, excessive administrative centralization, lack of rewards for good operation and maintenance, and widespread corruption in supporting organizations are the major causes of failed system maintenance (Howe & Dixon, 1993; Singh et al. 1993). Similarly, in the context of Nepal, most DWSs are unsuccessful due to lack of involvement

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by women during the planning stages, government supervision, supporting mechanisms for the handover of DWSs, and coordination among local water-user committees, local government, and district water-supply authorities (Sharma, 1998; Bhandari et al. 2005).

Although evaluation reports by governmental and nongovernmental agencies have highlighted the core problems for project sustainability, fundamental differences between rural market centers and villages have not been properly analyzed. The cultural, political, and socioeconomic situations—as well as the geographical settings—of Nepalese market centers and villages are quite distinct. Rural market centers tend to be located at the junction joining two or three villages and offer economic, social, administrative, and financial services (RUPP, 1999). Due to a subsistence economy and unemployment, internal migration pressure is increasing in rural market centers. The level of infrastructure in market centers has become a prime attraction for migrants and this trend has increased pressure on water supplies.

Many scholars claim that water-supply projects will be sustainable when consumers are willing to pay user charges that are sufficient to cover all costs in excess of grants. Willingness to pay (WTP) can be construed as an indication of the demand for improved services and their potential sustainability (Kaliba et al. 2003). In contrast, other observers have concluded that rural water systems are unlikely to be sustainable unless grants are available to finance most or all initial construction costs (Bohm et al. 1993). A study of Kathmandu's water supply shows that additional costs are almost twice as much as current monthly bills paid to the water utility (Pattanayak et al. 2005). Researchers recommend different models for WTP, but most assessments envisage a cost-recovery policy in the rural water sector (Whittington et al. 1990; Altaf et al. 1993; Howe & Dixon, 1993). Research has involved the use of the contingent valuation (CV) method to forecast WTP for potable water-supply services. Piper & Martin (1997) and Kaliba et al. (2003) report that households located far from water points evince higher WTP than counterparts living within proximate distance. Moreover, this relationship appears to be valid both for low-income users and where water quality and supply systems are poor.

According to government policy, the operation and maintenance costs of DWS projects in rural areas of Nepal should be covered by the community itself while the investment cost for such projects should be financed by the government or donor agencies (NPC, 1998). Communities may also contribute to project investment by providing labor, land, and local materials. Individual house connections or meter systems are not used in the rural water-supply system; therefore, grain or small amounts of cash can be raised from beneficiary households to cover the scheme's maintenance and operation expenses.

A sustainable water future depends on appropriate prices and the necessary resources need to come from project consumers (World Bank Water Demand Research Team, 1993; Whittington, 1998). However, Whittington et al. (1990) discovered that rural customers in Nigeria do not want to pay for water in advance or commit themselves to a fixed monthly payment due to their mistrust of public providers. Some scholars have focused on community-water education and the creation of organizational capacity to ensure project sustain-ability (Baker et al. 2006). The literature shows that water-user committees play a vital role in the sustainability of rural water schemes and that the enhancement of facilitation skills, the clarification of responsibilities, the improvement of transparency in decision making, and the augmentation of credibility are essential for making a committee trustworthy (Lopez-Gunn & Cortina, 2006).

According to Bohm et al. (1993), WTP for improved water services increases with income and wealth, family size, education, and dissatisfaction with traditional sources. In the same vein, a study on household demand for an improved water-supply system in Kathmandu shows that consumers' WTP for better service is increasing (Whittington et al. 2002). A similar study in Indian cities shows contradictory results and suggests that satisfied consumers are not willing to pay more for improved DWS schemes (Raje et al. 2002). Most scholars have focused on the financial sustainability of municipal (urban) or corporate water systems. The current study examines the variables that influence users' WTP for the operation and maintenance of rural DWS schemes in Nepal. This analysis also compares core problems on the basis of an institutional survey regarding the sustainable operation and maintenance of DWS schemes in the country.

Methods of Data Collection and Analysis

The Survey Instruments

A three-pronged survey instrument was applied in this study of drinking water schemes in Nepal. The methodology first called for informal discussions with key informants about the strengths and weaknesses of existing water-supply schemes and their management. In the second phase, a random institutional survey of water-user committees was conducted. The final stage of this process involved implementation of a systematic random survey of 205 Nepalese households.

Supply conditions refer to such factors as hours and timing of provision, quantity, tap pressures, and quality of water that were deduced from factor analysis. A five-point Likert scale—including points for not at all satisfied, not satisfied, partially satisfied, satisfied, and highly satisfied—indicated respondents' opinions on each of these factors. Also, a ranking question was included to find the level of importance that respondents assigned to each factor. Three major procedures—conjoint analysis, dichotomous choice, and the payment-scale approach—are popular for contingent evaluation (Baidu–Forson et al. 1997; Kaliba et al. 2003). To elicit WTP information from individuals, the dichotomous choice approach was applied. Responses were obtained on a dichotomous scale (yes or no) on the supposition that users would have to pay at minimum double the present amount (from Rs. 20–100 (US$1=Rs. 72) per month. Respondents' assessments of the trustworthiness of the water-user committees and the affordability of water charges were obtained in a similar manner.

Model

The most widely used model in CV studies is based on logistic regression. The model here uses variables of degree of satisfaction (DOS), trustworthiness of water-user committees (WUC), and affordability to describe users' WTP for water. Because of the dichotomous structure of the dependent variables (i.e., WTP) a non-linear prob-abilistic model was used to help estimate the probability of occurrences of an event as given by

$$\text{Probability (event)} = 1/1+e^{-z} \tag{1}$$

Where Z is the linear combination of variables X_1, X_2, X_3,…, X_n

$$Z = B_0 + B_1X_1 + B_2X_2 + \ldots + B_pX_p \tag{2}$$

The above probability expression can be transformed to determine the log odds in favor of the event as

$$\text{Log }\{\text{Prob (event)}/1\text{–Prob (event)}\}$$

$$= B_0 + B_1X_1 + B_2X_2 + \ldots + B_pX_p \tag{3}$$

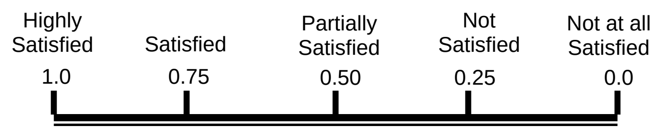
In the present context,

$$Z = B_0 + B_1\,(\text{DOS}) + B_2\,(\text{Affordability}) + B_3\,(\text{WUC Trustworthiness}) \tag{4}$$

It was assumed that the variable corresponding to the degree of satisfaction might have a negative influence on the WTP of water users. In other words, people with low satisfaction levels might indicate their WTP in anticipation that in the future their demands would be fulfilled, while those who were already satisfied might not be willing to pay.

Degree of Satisfaction

The composite index approach is also a simple and straightforward format that is widely used in planning and evaluation studies such as the human-development index and the rating index (Sullivan, 2002; Sullivan et al. 2003). Specifically, this satisfaction scale was developed on the basis of factor analysis to measure user satisfaction (Figure 1).



$$\text{AWI} = \frac{f_h(1.0) + f_s(0.75) + f_p(0.50) + f_n(0.25)}{ni * N}$$

AWI = Average Weighted Index
f_h = frequency of high satisfied
f_s = frequency of satisfied
f_p = frequency of partially satisfied
f_n = frequency of not satisfied
ni = number of items
N = total number of observations

Figure 1 Satisfaction scale.

Study Area and Data Collection and Analysis Methods

The literature often describes drinking water in just two types of DWS schemes: urban and rural. In fact, geographic location and accessibility of water can make a major difference in the livelihoods and living standards of rural residents. This study in Nepal was therefore carried out with two geographical categories of rural water-supply systems: village and rural market center. Villages are rural settlements without a market or any public facilities. In contrast, rural market centers are small communities with a market and public services. Village-market centers generally have more than three foot trails that meet within their boundaries. Usually rural market centers in Nepal have more than 100 households with teashops, schools, and a few government-service centers. The DWS samples were chosen from both villages and market centers. Due to the many INGOs and NGOs working in the drinking water field, the study area was chosen from two districts: Kavre from the mid-region of Nepal and Baglung from the western region of the country (Figure 2).

Figure 2 Study area.

Sampling

On the basis of information provided by the Department of Drinking Water Supply and Sewerage, we chose for this study the largest DWS schemes in the Kavre and Baglung districts (Table 1). The number of surveyed households was based on the project reports prepared by the DWS installation agencies. A sample size of 88 respondents was selected from a total of 771 market-center households. Similarly, a sample size of 117 respondents was drawn from a total of 1,327 rural village households,. This sampling methodology assumed that the expected rate of occurrence was not less than 90% at the 95% confidence level with a precision level of 3%. Following Arkin and Colton (1963), the sample size (based on a total of 2,098 households) was computed from the following formula.

$$n = \frac{NZ^2 * p * (1-p)}{Nd^2 + Z^2 * p\,(1-p)} \qquad (5)$$

Where,

n = sample size
N = total number of households
Z = confidence level (at 95% level Z = 1.96)
p = estimated population proportion (0.5, this maximizes the sample size)
d = error limit of 5% (0.05)

Data Collection

Prior to data collection, the lead author held a meeting with selected local residents, community leaders, officials from the district water-supply offices, representatives from local NGOs, contact persons, and members of the village-development committees (VDC). During the session the villages to be included in the survey were identified and this determination ensured the cooperation of relevant individuals from the respective villages and communities throughout the field-survey period. This initial meeting served as a confidence-building measure. Because they were well informed of the research goals, villagers and WUC members involved themselves actively in participatory rural appraisal sessions, discussions, and WTP workshops. The four locally hired enumerators visited households through random sampling and interviewed either household heads or women in charge of household finances.

Table 1 Sample water-supply projects in rural market centers and rural villages.

DWS projects in rural market centers	Village-development committees	Benefited HH	Subsample size	Year completed
Todke DWS (INGO)	Dudhilabhati Ward No. 5	80	14	1994
Bhulkemul DWS (GO)	Narethanti Ward No. 1, 3	208	25	1989
Bajange Dahare DWS (NGO)	Bhimpokhara Ward No. 6	57	7	1996
Shipaghat DWS (INGO)	Panchkhal Ward No. 3, 5	135	12	1994
Chalal DWS (GO)	Chalal Ganeshthan Ward No. 1, 8, 9	183	20	1992
Mechhe DWS (NGO)	Kushadevi Ward No. 1, 2	108	10	1995
Totals		771	88 (11%)	
DWS projects in rural villages				
Gahate DWS (INGO)	Dagahatundanda Ward No. 6, 7	166	20	1993
Tangram DWS (GO)	Tangram Ward No. 6, 7, 8, 9	501	28	1992
Bhim Pokhara DWS (NGO)	Bhimpokhara Ward No. 5	192	20	1994
Geldung DWS (INGO)	Dhumkharka Ward No. 8, 9	142	14	1994
Bhamarkot DWS (GO)	Panchkhal Ward No. 1, 2, 3, 4	135	15	1994
Jalachiti Taukhal DWS (NGO)	Taukhal Ward No. 4	191	20	1990
Totals		1327	117 (9%)	
Grand Totals		2098	205 (10%)	

Data Analysis

Data were analyzed using a standard social science statistical software program. The degree of satisfaction with drinking water services installed by different development agencies was measured using the Likert scale, a scaling approach used in social research through standardized response categories on surveys in which the concept of measuring an object is assumed to be one-dimensional (Likert, 1932; Trochim, 2001). The survey data were then analyzed by binary logistic regression.

The scale's internal consistency was measured by the reliability coefficient, Cronbach's alpha (Cronbach, 1951), that ranged from 0 to 1; the larger the value, the greater the reliability. Logistic regression was then used to determine whether such demographic variables as gender, age, education, and income helped to explain perceptions regarding WTP. Bivariate data categorical responses were then analyzed using Pearson's χ^2 distribution test to discern if two variables were independent of each other (Tessler & Warriner, 1997). If the two variables were not dependent ($p < 0.05$), Cramer's V was employed as a measure of association (Bishop et al. 1975). The value of Cramer's V ranged from 0 (no association) to 1 (perfect association). A Wald test was used to assess the statistical significance of each coefficient (β) in the model.

Results and Discussions

Exploring Factors Related to Consumers' Satisfaction

Factor analysis was employed to select the satisfaction component among highly correlated items. This technique is often used to examine underlying patterns (reliability) or to identify relationships among a large number of variables and to determine whether the information can be summarized (validity) into a smaller set of factors or components (Kim & Muller, 1978).

The data matrix has sufficient correlation to justify interrelated sets of variables. If visual inspection reveals no substantial correlation greater than 0.3 then factor analysis is probably inappropriate. At the first stage, variables were selected and assessed in order of their significance of covariance (< 0.5) with at least a 0.01 confidence level. The principal components method was used to analyze the data.

Factor analysis reveals that water sufficiency, reliability of water supply, trustworthiness of the water-user committees, convenient water-point location, water quality, and water pressure (flow rate) have become prime indicators (principal components) of users' degree of satisfaction (Table 2).

Table 2 Factor analysis based on performance-related indicators.

Variables	Items	Factor-loading Degree of Satisfaction
WATERSUFF	Water sufficiency	0.852
RELIABILITY	Reliability of water supply	0.790
TWUC	Trustworthy water-user committee	0.763
CONWPL	Convenience of water-point location	0.720
QUALITY	Quality of water supply	0.693
PRESSURE	Pressure of water supply	0.667

The set of items identified through factor analysis was combined to form a scale measuring users' preference toward a high level of satisfaction.

Users' Priorities and Satisfaction Levels with DWS Services

Sixty percent of the respondents in the household survey were women, the traditional managers of DWS schemes. Respondents over 50 years of age were designated "old" so as to compare different possible age-group views.

A non-parametric, one-sample χ^2 test was run to examine if any association existed among these categories. In Table 3, B is a logistic regression coefficient, df is the degrees of freedom, SE is the standard error, and R indicates the relative contribution of each dependent variable to the model in explaining the variance of the dependent variable. Logistic regression indicated that no significant association existed between the degree of satisfaction and respondents' demographic characteristics.

Table 3 Logistic regression of the relationship between demographic variables and users' degree of satisfaction.

Variables	B	SE	Wald	df	Sig.	R
Gender (male)	0.6068	0.2932	4.2840	1	0.0385	0.0893
Age (older)	-0.6975	0.2924	5.6919	1	0.0170	-0.1136
Class (wealthier)	0.2053	0.2900	0.5013	1	0.4789	0.0000
Education (literate)	0.2612	0.2971	0.7726	1	0.3794	0.0000

On the basis of average weight index analysis, the study reveals that preferences differ between rural market centers and villages. Users from the rural market centers are more concerned about water sufficiency, water pressure, and convenience of water-point locations. In contrast, among rural village users, reliability, trustworthiness, and convenience of water-point locations are the major concerns. Inconvenient water-point locations are a common problem in both areas. Dissatisfaction with WUCs is relatively high in rural areas (Table 4).

Table 4 Weightings on indicators of satisfaction level.

Indicators	Rural market centers	Stress for improvement	Rural villages	Stress for improvement
TWWUC	0.2097	6	**0.1185**	**1**
QUALITY	0.2001	5	0.2104	5
CONWPL	**0.1628**	**3**	**0.1249**	**2**
WATERSUFF	**0.1038**	**1**	0.2132	6
PRESSURE	**0.1330**	**2**	0.2001	4
RELIABILITY	0.1906	4	**0.1329**	**3**

Note: Bold face indicates users expressing high levels of concern for the improvement.

A recent analysis of water quality shows that the reservoirs and intakes of most of the DWSs in Nepal have pathogen contamination, particularly in the rainy season (Bhandari & Wickramanayake, 2001). However, the current study shows that users from both villages and market centers are less concerned about water quality. The authors conclude that awareness about the importance of safe water is insufficient since users believe that piped water is clean.

Usually the WUCs for rural DWS schemes face problems in the rainy season. The flooding of intake structures and the washout of supply pipelines are periodic problems during this time of the year, resulting in consumer skepticism about water-supply reliability. During the survey of engineering specifications, discussion with WUC members revealed that they were unaware of the importance of the location of their water points. Consequently, some water points are located on private lands and others are in the middle of congested villages. This arrangement creates inconveniences in fetching water, problems with the drainage of wastewater, and fear of landslides during the rainy season. Likewise, WUC members in the rural market centers mentioned that due to burgeoning construction of new houses they now face a water shortage during the dry season.

Synthesis of Group Discussion

According to the manual for rural DWS schemes in Nepal, the WUC has authority to raise money for maintenance and operation from each household. Outside of government-installed DWSs, the WUCs in the study areas raise funds annually and some households pay their share in grain (25–40 kgs) to the village-maintenance operator.[1] Relatively poor families have been exempted from water tariffs for most DWS schemes in the country, a provision that is usually implemented during project installation. The WUC is responsible for evaluating and monitoring these issues.

The WUCs must also pay wages for village-maintenance workers. According to the rural DWS institutional survey, on the basis of the past three years (2001–2003), the WUC of NGO-installed projects are raising Rs. 240–600 annually from each household for this purpose. Similarly, INGO-installed projects have charged Rs. 600–1200 per year for maintenance and operation. Government-installed systems have no capacity to raise money. However, all water schemes have bylaws that users should be responsible for the repair or maintenance of the water faucet (tap) and the cleanliness of their own tap-stand platform. This project found that all WUCs in the rural market centers have bylaws requiring that all households should pay a water tariff of Rs. 50–150 per month or Rs. 600–1800 annually. The WUCs in the market centers indicated that they experienced a 10–15% default rate; however, they are trying to convince and remind all residents of their responsibilities at each meeting. On the other hand, the WUCs in the rural villages reported that more than 50% of their residents had not paid water dues for two to three years. The WUCs stressed that they have no authority to punish or force payment. Government authorities are also located far from the communities and the appeal procedure is complex and lengthy. The market-center WUCs realized that such issues need to be settled by community consensus and highlighted that people perceive an extra burden due to a lack of awareness about the importance of safe drinking water.

One of the survey instruments used in this study involved group discussions with the key DWS stakeholders. Different views and problems were identified in exchanges with the members of the WUCs in rural market centers and rural villages. According to the ranking technique, rural villages encounter the following leading problems:

1. Insufficient collection of money (water tariffs) from water users for maintenance and operation.
2. Difficulty retaining maintenance workers in project areas since they often leave the villages to search for higher paying jobs.
3. Frequent damage by natural disasters such as landslides, floods, and forest fires.

The WUCs in the market centers report the following major problems:

1. During peak hours there are a lot of users at each water point and households located far from the piped tap stands must search for other unprotected sources.

[1] Local market price of grains per kg = Rs. 10–15

2. The majority of households use water in kitchen gardens and encounter an acute shortage for three to four months during the dry season.
3. Water pressure in taps is not sufficient in more elevated settlement areas.

The results show that the market-center WUCs are successful administering DWS projects, but they face technical problems. Due to unexpected household growth and increasing health and hygiene awareness, the water consumption rate is high in the market centers. On the basis of the group discussion, the average consumption rate is 60 liters per capita per day (lpcd) in the market centers and 45 lpcd in the rural villages. Engineers in the district explained that they used 45 lpcd in general in the design of rural DWS projects.

Assuming that a pour-flush latrine needs an average of 2–3 liters of water for every flush, a person would need 12–18 liters of water each day for flushing purposes alone. The minimum criterion of either 25 or 45 lpcd is meant for domestic demands—drinking, cooking, bathing, washing clothes and dishes, latrine flushing, watering animals, and maintaining sanitary conditions in the latrine, bathroom, kitchen, and overall household. The expansion of rural infrastructure significantly influences quality of life and, as a result, increases the consumption of drinking water (Ghimire, 2002). Under such circumstances, supplied water should meet basic requirements, including the quantity essential for maintaining minimum sanitary conditions in latrines and household premises. The conclusion is that an assessment of demand should be revised on the basis of settlement patterns and their evolving development.

Engineers have projected population outward for 15 years on the basis of the national growth rate rather than in the context of the specific expansion of the market centers. Village WUCs have managerial problems and sufficient institutional capacity is essential before handing projects over for local operation and control.

Satisfaction Level vs. Willingness to Pay

The first assumption to be tested was whether satisfaction level affects users' WTP for the operation and improvement of DWS schemes. Data were analyzed on a category-wise basis and regression coefficients were obtained as reported in Table 5. In both categories, χ^2 values are quite significant, indicating the goodness-of-fit of the models. Another measure of goodness-of-fit is the percentage correct classification. In the market-center category, the prediction accuracy is about 93%, while in the rural category it is 89%. The significance of Wald's statistic shows values less than 0.05 (assumed significance level), implying that the variable sufficiently deviates from zero. The exp (B) value corresponding to each variable suggests significant changes in both categories. The exp (B) value corresponding to each variable indicates its respective contribution to the odds in favor of WTP.

The values corresponding to DOS in both categories show that changes in the satisfaction level hardly have an impact on the probability estimates of WTP. With respect to the variable for trustworthiness, its effect on WTP is quite pronounced as reflected by a very high exp (B) value in the market-center category. Most of the respondents in this classification stated that there were insufficient managerial skills due to poor training and support. A change in the value of trustworthiness from 0 to 1 increases the odds in favor of WTP by nearly 19 times. By comparison, in the village schemes, the impact of satisfaction on WTP is relatively small. However, in this category trust in the management system with regard to project planning and execution dominates the odds in favor of WTP. This result indicates that user-satisfaction level influences the probability estimates of WTP. This outcome contrasts to findings reported by Raje et al. (2002) for the Mumbai (Bombay) metropolitan water supply.

Table 5 Logistic model for the two categories.

Category	Variable	B	SE	Wald	df	Wald Sig.	exp (B)
Rural market centers*	DOS	2.9578	1.0990	7.2399	1	0.0071	19.2551
	Affordability	1.5184	0.7887	3.7061	1	0.0542	4.5649
	Trustworthy	2.9475	1.1256	6.8567	1	0.0088	19.0582
Rural villages**	DOS	1.9345	0.4800	16.2414	1	0.0001	6.9209
	Affordability	1.1192	0.4669	5.7469	1	0.0165	3.0624
	Trustworthy	2.2904	0.5512	17.2660	1	0.0000	9.8786

Log likelihood* = -418.46
Wald chi-square goodness of fit* = 196.04
Log likelihood** = -306.14
Wald chi-square goodness of fit** = 143.56

Table 6 Willingness to pay corresponding to different satisfaction levels.

Satisfaction category	Rural market centers			Rural villages		
	N	W	NW	N	W	NW
Not satisfied	12	5 (41.7%)	7	10	3 (30.0%)	7
Partially satisfied	31	10 (32.3%)	21	55	19 (35.1%)	35
Satisfied	36	27 (75.0%)	9	46	30 (65.2%)	16
Highly satisfied	9	7 (77.7%)	2	7	6 (85.7%)	1
Total	88	49 (55.7%)	39	117	58 (49.6%)	59

Note: N = Number of respondents, W = Willing to pay, NW = Not willing to pay

This study reveals that satisfaction level, affordability, and WUC trustworthiness have a significant influence on the probability estimates of WTP (Table 5). The statistical analysis shows that user satisfaction and trustworthiness are highly influential indicators in the allocation of maintenance and operation charges in DWS schemes.

The correspondence of WTP to different satisfaction levels shows that a high percentage of satisfied respondents in both schemes is willing to pay for maintenance and operation (Table 6). A high percentage of poorly satisfied and partially satisfied users reduced WTP for the upkeep of DWS schemes. Group discussions with the members of WUCs in both rural villages and market centers indicated that households situated close to a traditional water source are reluctant to participate in a community DWS. Furthermore, because of the often inconvenient location of the water points, they are not willing to pay or commit to improving the system.

In this context, two important issues should be considered before allocating water rates. First, user-satisfaction level, WUC trustworthiness, and affordability are crucial factors in determining WTP. Second, the convenience of water-point locations needs to be reviewed to improve both types of DWS schemes.

Conclusion

This study focuses on the operational sustainability of rural water-supply systems in Nepal. The Department of Drinking Water Supply and Sewerage, with the assistance of the United Nations Children's Fund and bilateral aid organizations, developed a blueprint that is often used by GOs and NGOs for project implementation. The analysis shows no significant association between satisfaction and respondent variables such as gender, age, economic status, and education. The principal component analysis shows that water quantity, reliability, WUC trustworthiness, convenience of water-point locations, water quality, and water-flow pressure are the most crucial and correlated variables in the performance of water-supply systems.

The study also indicates that users' preferences differ between rural villages and market centers regarding the improvement of existing systems. On one hand, users in market centers strongly prefer water quantity, adequate flow pressure, and convenient water-point locations. On the other hand, users in rural villages place high priority on good operation and maintenance management, convenient water-point locations, and reliability of supply. Therefore, water engineers and planners in Nepal ought to consider villages and rural market centers separately when designing and planning rural water-supply programs.

Although the issue of inconvenient water-point locations is the same in both types of DWS schemes, the study concludes that problems differ in rural settings. Village DWS schemes face institutional inadequacies such as weak managerial skills on the part of the WUC and, in contrast, market centers face technical obstacles such as water shortages and insufficient pressure head in the supply system. In this regard, the study indicates that enhancement of institutional capacity at the community level and water education are essential for the sustainability of DWS projects in rural villages throughout the country.

The Nepalese government allocated Rs. 8.26 billion (approximately US$115 million) in fiscal year 2003–2004 to implement various water-supply and sanitation projects (NPC, 2003). However, due to weak institutions, after a few years these projects again will require repairs or rehabilitation. In the absence of diagnosis of core problems in rural DWS schemes, the same trends will be repeated again and again. Because the rural water-supply program has no provision to install meters, grain or cash collection from each household is the main monetary source for maintenance and operation. The study shows that DOS highly influences WTP for maintenance and operation in both settings. Satisfied and highly satisfied users of market center and rural village DWS schemes evince a willingness to pay for improved water systems. This finding indicates that good service and consumer satisfaction can attract more revenue to upgrade and operate existing infrastructure.

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ARTICLE

The ecosystem of expertise: complementary knowledges for sustainable development

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This article critically examines the approach of technical experts, including engineers, natural scientists, architects, planners, and other practitioners, who are attempting to create more sustainable forms of economic development, environmental protection, and social equity. The authors identify four principal characteristics of expertise–ontological assumptions, epistemological approaches, power inequalities, and practical issues–and employ this framework to test the capability of traditional experts to deliver sustainable development. The authors then provide four alternatives to conventional forms of expertise: the outreach expert who communicates effectively to non-experts, the interdisciplinary expert who understands the overlaps of neighboring technical disciplines, the meta-expert who brokers the multiple claims of relevance between different forms of expertise, and the civic expert who engages in democratic discourse with non-experts and experts alike. All of these alternative forms are needed to manage the often-competing demands of sustainable development projects and they can be described collectively as an "ecosystem of expertise."

KEYWORDS*:* sustainable development, economic planning, ecosystem management, social change, political science, interdisciplinary research

Introduction

The dominant role of technology in modern societies requires the public to rely on individuals with specialized knowledge to invent, design, manufacture, and maintain increasingly complex artifacts and networks. The modern city provides numerous examples of society's reliance on technology. Complex networks of transportation shuttle residents between their places of work, home, and play; wired and wireless communication systems transmit information at the speed of light; and sophisticated water networks regulate the hydraulic metabolism of the city. Clearly, many interrelated technologies are necessary to maintain our daily lives and to support political, economic, and social frameworks. This article refers collectively to the individuals who possess technical knowledge to design, build, and maintain these technologies as *technical experts*. It is no surprise that this "class" has an indispensable role as more sophisticated technologies require increasingly specialized individuals who understand the underlying scientific and technical principles.

In recent decades, it has become clear that civilizational progress, to a large extent facilitated by technological developments, has been accompanied by unintended consequences that threaten humanity in the long term. Global poverty levels, climate change, social exclusion, accumulating toxins, and other issues are often subsumed under the heading of unsustainable human practices. It would be simplistic to indicate a linear causal relationship between technological development and these problems, but they are both, at the least, prominent features of the modern world. Thus, efforts to create more sustainable development require an examination of the opportunities and dangers of involving technical experts. This is the overarching question we pursue in this article. We explore the meanings and problems associated with expertise and sustainability to understand the implications of the compound term "sustainability expert" from a transdisciplinary perspective. The discussion highlights some of the inherent shortcomings of conventional expert-driven approaches to sustainability as well as possibilities for more effective applications of sustainability expertise.

The Expert in Modern Society

The rise of "expertocracy" is rooted in the Enlightenment, when experts began to acquire–or were granted–the power to shape and direct societies via scientific and technological development (Brand, 2005a). And their efforts were very successful indeed. Large complex systems, including gas, electric, water, sewage, and transit, were designed and constructed by technical experts in American, British, and European cities in the late-nineteenth century, making engineers highly influential in public policy (Seely, 1996). Technical experts served as the "human face" of technology, symbolizing efficiency, stability, functionalism, objectivity, and progress, while seemingly enacting the values of modern civilization (Hickman, 1992).

The privileged status of the technical expert is embedded in most modern Western cultures. For example, vernacular German includes a number of proverbs about the superiority of the engineer, such as *dem Ingeniör ist nichts zu schwör* (no task is too difficult for the engineer), exemplifying the engineer as a symbol of national identity. The slogan "Made in Germany" was partially inspired to connect the recovering post-World War II nation to the earlier achievements of Werner von Siemens and other "genius inventors." In the United States, a related trend at the turn of the twentieth century replaced the cowboy with the engineer as the symbolic figure of national culture (Hickman, 1992). Thayer (1994) describes the importance of the expert to the collective American psyche as follows:

> We have never lost the myth that technological innovation and invention is America's rightful spiritual territory…Clearly Americans place greater social value upon those people whose occupations involve scientific discovery and technological development than on those who deal with social issues or problems. Starting salaries for engineers are roughly twice those of social workers or teachers.

The most conspicuous technical experts in industrial societies include natural scientists and engineers whose specialized knowledge stems from the formal study of a scientific or technical discipline.[1] Subsequently, their social power is derived either from their professional status (as is the case with engineers) and/or from their adherence to a scientific method (as with natural scientists).

Ironically, the pursuit of expertise has the social effect of elevating the individual to semi-god status while also narrowing these individuals' perceptions through specialization. Technical experts and, in fact, all experts become adept at microscopic and specialized analysis at the expense of macroscopic, holistic perspectives. Cliff Hague (1997), former president of the UK Royal Town Planning Institute, remarks in this context that

> Twentieth century higher education and research has been dominated by analysis. Ever more sophisticated ways have been found to break experience down into its constituent parts. New disciplines have been built by reducing scope while deepening, and making more particular, the knowledge and methodologies.

The sacrifice of breadth for depth seems the logical price to pay for the acquisition of expert knowledge. Such a strategy also facilitates the division of labor among different disciplines. The jargon of specialists, their concepts, terminologies, and theories, serve as heuristic proxies–Joerges (1999) might say *LogIcons*–for things (physical or mental) and therefore steer the perception and analysis of evidence. Dedicated experts thus can develop a solipsistic or hermetically sealed notion of a problem and, accordingly, of a solution. Louis Menand (2001), drawing on the philosophical writings of Oliver Wendell Holmes, characterizes the problem with modern modes of thinking as follows: "we know we're right before we know why we are right. First we decide, then we deduce." Those who exhibit this all too common symptom of expertise tend to scan the horizon of problems until they find a fit with the type of solution they can offer. The colloquial equivalent to this observation goes like this: For someone whose only tool is a hammer all problems begin to look like nails.[2] In other words, epistemology precedes ontology when, ideally, it should be the reverse.

Critiques of Expertise

This tendency for technical experts to adopt specialized worldviews, and the drawbacks that modern forms of technical expertise entail, has not gone unchallenged. Criticism and analysis of expertise has come from scholars in many disciplines including sociology (e.g., Collins & Evans, 2002), political science (e.g., Bimber, 1996), political philosophy (e.g., Turner, 2001), risk assessment (e.g., Wynne,

[1] Experts from other fields, including but not limited to architecture, planning, policy, and law are often not perceived to be technical experts, but we include them here in our general notion of individuals with specialized technical or scientific knowledge.

[2] As interdisciplinary scholars, we are of course not immune to analogous criticisms that would accuse us of portraying sustainability as a challenge that requires all disciplines to work together simply because our services would be sought after in such a scenario. Although we have no means of refuting this allegation, we hope that reflection upon this danger sets us apart from unrepentant solipsists.

1996), environmental policy (e.g., Fisher, 2000), and feminist studies (e.g., Haraway, 1991). Below we have clustered these criticisms into four main groups: ontological assumptions, epistemological approaches, power inequalities, and practical issues. These groups do not include all critiques of expertise, but this typology summarizes some of the principle problems revealed in the literature.

The *ontological* assumption of traditional forms of expertise is that of a *knowable* and unequivocally *re-presentable* world "out there." Harding (2000) describes this stance as the dream of "one world, one and only one possible true account of it, and one unique science that can capture that one truth most accurately reflecting nature's own order." Closely related to this assumption is the idea of universality, the hope that knowledge can be free from the shackles of context, its validity floating freely above time and space. Knowledge, then, manages to overcome immanence and reaches up to the realm of transcendence. This is the basis of a positivistic ontology, the idea that the world is a knowable place and, through knowledge, we can resolve its problems. Accordingly, experts share a teleological notion of progress and believe in the theoretical possibility of ultimate solutions that can be discovered by following the "proper path of science" (Moore, 2001). Those who adhere to this ontological position naturally dislike the counterarguments of poststructuralist and postmodernist scholars who argue that science is plural rather than unitary (Harding, 2000). Such a pluralistic perspective is incongruent with conventional scientific methods that call for the reduction to individual, discrete units of study.

While the boundary between ontology and epistemology is blurry at best and deceptive at worst (see Lincoln & Guba, 1985), we draw this distinction to emphasize the multiplicity of knowledge as well as the multiplicity of *forms of* knowledge. For example, competing expert knowledges are frequently marshaled by property developers and nongovernmental organizations (NGOs) to deliberate over the implications of environmental impact assessments (EIAs). In this regard, Fischer (2000) argues that

> This newer configuration of circumstances redirects our attention more to the limits of our knowledge, in particular to the unanticipated consequences resulting from the application of modern technologies. Such uncertainties have shaken the public's faith in the experts. After having long trusted experts generally, citizens are confronted with the task of choosing which experts to believe and trust.

The problem of competing *formal* expertise is exacerbated by the existence of experiential, local, or tacit knowledge that arises from personal experience and exploration outside the confines of educational institutions and without full adherence to the scientific method. Scott (1998) refers to these different forms of knowledge in his distinction between *techne* and *metis*. *Techne* "is characterized by impersonal, often quantitative precision and a concern with explanation and verification," while *metis* represents indigenous knowledge, meaning, experience, and practical results. Similarly, as Lane & McDonald (2005) explain, Levi-Strauss and Feyerabend are significant among the scholars who have observed that the "construction of [indigenous] knowledge is holistic, territorially oriented and concrete, whereas western science is abstract, reductionist, and separates the human from the natural." Lane & McDonald sum up their perspective on technical knowledge by stating that "technical knowledge simultaneously sharpens our focus and obscures our vision."

Recognizing different forms of knowledge poses the question of whether they are treated equally. Not surprisingly, *power inequalities* do exist frequently, if not systematically, between the possessors of differing knowledge forms. Holders of experiential knowledge are typically not granted a seat at the decision table due to favoritism for formal knowledge inherent in our decision-making institutions. At this juncture of the debate, the critique of technical expertise brings politics to the forefront of technical decision making. While many good reasons exist to depoliticize public environmental disagreements through professional mediation, these so-called deliberative formats favor technical experts over activists, citizens, and other stakeholders. The only acceptable language for use in such extra-parliamentary discussions is the scientific one and this directs the deliberative process toward technical and scientific, rather than democratic conclusions (Fischer, 2000). Furthermore, stakeholders without formal knowledge are portrayed as "incapable of grasping the technical nuance and methodological complexity of science" (Kleinman, 2000). From this perspective, Turner (2001) argues that "expertise is treated as a kind of possession which privileges its possessors with powers that the people cannot successfully control, and cannot acquire or share in."

Related to democratic concerns of technical expertise is the inclination of experts to frame technical problems through the eyes of their elite employers (Fischer, 2000). De facto, technical experts often end up on the side of governmental and corporate power and they are, in effect, the "perceived handmaidens in science and technology" (Foreman, 1998), at times even working against the public that they are ostensibly chartered to serve. A response to the institutional bias of experts has been the rise of counterexperts, individuals who can dispute technical experts on their own terms (Yearley, 2000). The emergence of the counterexpert is especially prevalent in environmental disputes because of the high degree of uncertainty that they engender. Environmental NGOs frequently employ counterexperts to muddy the scientific waters by introducing competing interpretations of a particular scientific or technical problem.

In addition to issues of epistemology, ontology, and power, there are *practical problems* that cannot be solved solely through technical expertise. For example, Beck (1992) argues that the question of whether we should use nuclear energy can never be answered with an objective "yes" or "no" because issues of risk and risk perception require "soft," culturally specific responses. In other words, values and politics are embedded in sociotechnical developments (and vice versa) and no *pareto optimum* calculation can ever offset a collective preference for caution. Some experts attempt to portray such opinions as irrational and seek to educate objectors about the "facts," or even ignore those who cannot see how things "really are." Such a blunt technocratic and expertocratic approach is not merely an ideological concern. Peretz, Tonn, & Folz (2005) observe that there are "causal and temporal relationships between decision-making *processes* and program *performance*" (emphasis added). The buy-in of stakeholders is just one of the factors that externally imposed measures cannot guarantee. A top-down approach also leaves untapped the stochastic effect of harnessing the creativity of thousands of individuals. Based on Oliver Wendell Holmes' notions of free expression and thinking as a social activity, Louis Menand (2001) succinctly states that "we need the resources of the whole group to get us the ideas we need." Lane & McDonald (2005) summarize these pragmatic considerations as "harnessing local assistance and energy, and incorporating the ideas and wisdom of local people."

An even more practical problem is that decisions that are made using scientific methods require enormous amounts of highly precise data. But such voluminous amounts of information typically require expensive and lengthy gathering processes. And even if all required data were obtainable, and even if they could be fed into an appropriate complexity-preserving model, developing such a model would likely require too much time and too many resources to resolve problems that demand more immediate action. This condition, often called "paralysis by analysis," points to the sometimes incapacitating effects of decision making based on scientific and technical analysis.

The Challenge of Sustainability

The challenges to technical experts in modern societies become more difficult when we consider the notion of sustainability or sustainable development. Sustainability has multiple meanings and interpretations, though most groups that subscribe to the notion agree that it is a holistic approach to solving complex, interrelated, and multi-dimensional problems. Dryzek (1997) observes that the main accomplishment of sustainability has been "to combine systematically a number of issues that have often been treated in isolation, or at least as competitors." In other words, the principle advantage of sustainability is its pluralistic, inclusive approach to problem solving, as opposed to conventional problem solving with its limited focus on specific elements that overlooks unintended consequences as well as the proverbial "big picture."

The interdisciplinary genealogy of the sustainability agenda is–for better or worse–a result of its conceptual comprehensiveness. A direct lineage can be drawn to concerns about the continual use of forests that was articulated early on by John Evelyn (1620-1706) in England, followed shortly by his German colleague Hans Carl von Carlowitz (1645-1714). Both argued that one should not harvest more wood than a forest yields, and thus these far-sighted naturalists might be characterized as *proto-sustainability* advocates.

The conceptual composition of the sustainability discourse also contains elements from nineteenth-century England's calls for improved public health, championed by urban social reformers such as Edwin Chadwick (1800-1890). These individuals recognized that the poor health conditions of the British working class threatened economic development and, thus, they highlighted the link between sanitary conditions, human health of city residents, and economic prosperity. Even the work of physicists is reflected in the modern sustainability discourse, most notably the Second Law of Thermodynamics. This law, first formulated by Rudolf Clausius (1822-1888), stipulates that energy must be managed economically to protract the inevitable heat death of the universe, also known as entropy. Acting sustainably is thus interpreted as acting in a manner that minimizes entropy.

Finally, Ernst Haeckel (1834-1919) provided a crucial insight in his book *Generelle Morphologie* in which he introduced the term *ecology*. In Haeckel's conception, living beings are inherently linked to their environment, implying that any damage to one part of an ecosystem affects the whole. We can identify a number of other disciplines and thought traditions underlying current discourse that clearly ground sustainability in interconnectedness.

Based on the interdisciplinary character of current sustainability discourses, it is not surprising that influential exemplars of sustainability scholarship and activism are conceptual hybrids that do not fit within traditional disciplinary boundaries.[3] A classic example is Rachel Carson's book *Silent Spring* (1962) that addresses not only health concerns and ecological problems of contaminated ecosystems, but also issues of environmental justice and freedom of information.[4] At times, the plurality of angles, concerns, and interests embodied in sustainability debates devolve into a confusing cacophony. This is a significant disadvantage in communicating sustainability's essence. A number of advocates have therefore attempted to distill sustainability to its elementary building blocks, a stratagem that inevitably runs the risk of trading richness for sloganistic value–the notorious problem of the lowest common denominator. Among the frequently cited distillates is the notion of widening the spatial and temporal horizon of human activities. In other words, we should not only consider the immediate effects of our actions, but also attend to ramifications in other parts of the world and in the long-term.

Perhaps the most commonly discussed explanation of sustainability is the *Three E* model that makes use of the triad of *E*conomic viability, *E*nvironmental protection, and social *E*quity.[5] The model illustrates the challenge of simultaneously accommodating a multiplicity of competing demands. In other words, the openness of the sustainability concept to various claims and concerns comes at the price of compromise. Campbell (1996) highlights a crucial implication of this model by identifying the inherent conflicts between each pair of **"**Es**"** and the need for techniques to effectively resolve these tensions. As such, sustainable development cannot be the exclusive task of experts–technical or otherwise–because the management of conflict toward successful outcomes requires a "restless, dialectical process" of open discussion and negotiation (Healey, 2004).

Recognizing that the sustainability discourse is a negotiation between competing interests focuses attention on the inherently political nature of creating more sustainable societies. As Prugh and colleagues (2000) note, "sustainability is provisional; it is subject to multiple conceptions and continuous revision, the very stuff of politics." Sustainability is also locally specific or, as Guy & Moore (2005) argue, "more a matter of local interpretation than of the setting of objective or universal goals." Identifying the most suitable political system to facilitate successful conflict resolution and amicable exchange of interpretations then becomes a pressing concern for sustainability advocates (see Moore & Brand, 2003).

All forms of liberal democracy practiced in the Western world today rely heavily on technical expertise to tackle sustainability problems (see Tate & Mulugetta, 1998). Technical experts are tasked with developing more efficient or effective technologies to overcome stakeholder conflicts. For example, improved renewable energy technologies (solar, wind, biomass) are seen as key to resolving energy problems, challenges with chemical toxicity are to be resolved through developing less toxic chemicals (green chemistry), and so forth. This is the underlying message of advocates of ecological modernization in northern Europe and green business in the United States who argue that industrialized society's harmful aspects can be expunged through more effective science and technology applications (for example, see WCED, 1987; Hawken et al. 2000; McDonough & Braungart, 2002). Today, the *technical fix* approach to sustainable development is the dominant model in industrialized countries because it retains the existing power of political and economic elites. In this regard, Hajer (1995) criticizes ecological modernization as a modernist, technocratic strategy that does not require structural change, while Dryzek (1997) observes that "in its most limited sense, ecological modernization looks like a discourse for engineers and accountants."

The technocratic approach to sustainability is strongly criticized for its overt and allegedly naïve embrace of deterministic solutions to problem solving and its reliance on existing capitalist policies.[6] These critiques originate from opponents of capitalism, as well as from advocates of social justice, democratic politics, feminist studies, and critical theory, whose shared goal is to make existing power relationships more democratic and equitable. As can be expected, the ingrained position of many technical experts comes under fire because of their alignment with those in power. Critics of the technophilic approach to sustainable development do not argue for the wholesale abandonment of technical expertise, but contend that technology should be directed by

[3] For a recent discussion of hybrids, see Härd & Jamison (2005).

[4] Gary Kroll (2004), a historian who studies science and engineering ethics, describes Carson's book as "cut[ting] against the grain of…scientism, and the technologically engineered control of nature."

[5] This is also referred to as the *Three P* model (people, prosperity, and planet) or the *Triple Bottom Line*. For example, see Zimmerman's (2005) brief discussion of the recent U. S. Environmental Protection Agency program that focuses on operationalizing the Three P concept.

[6] For a succinct critique of ecological modernization and green business, see Schatzberg's (2002) review of *Natural Capitalism: Creating the Next Industrial Revolution* by Paul Hawken, Amory Lovins, & L. Hunter Lovins.

society as a whole rather than imposed by powerful elites. Such a bottom-up approach emphasizes the creation of political communities to deliberate on conflicts and to transform them via equitable and lasting solutions.

The Sustainability Expert?

Those who accept the deliberative model of sustainability will probably agree that classical notions of expertise do not optimally *fit* sustainable development. In other words, we should be very careful when employing the term "sustainability expert." Does this mean that there is no such thing as sustainability expertise? If we are convinced that we need people skilled at understanding and employing sustainability principles, we are compelled to return to the very concept of expertise and renovate it to better align with sustainability. Four types of experts seem possible for this purpose: the outreach expert, the interdisciplinary expert, the meta-expert, and the civic expert. Each makes different contributions to resolving the dilemma of applying technical expertise to sustainable development.

The Outreach Expert

One response to the eroding credibility of technical experts has been to call for a more "informed" and "scientifically literate" public. The movement behind this idea is frequently referred to as the "public understanding of science" where the intent has been to improve the communication of scientific and technical knowledge to the public and to "educate" the citizenry about the primacy of technical knowledge (see Wynne, 1995). Jamison (2005) argues that "using science and technology appropriately means, for one thing, that we know how to talk about it and that we have what might be called a collectively shared understanding of the relevant science or technology, that is, that we are scientifically literate." One model of imparting scientific and technical expertise on the public is the science shops in the United Kingdom, the Netherlands and other European countries (see Irwin, 1995). The concept has also been translated into the practices of several universities such as the Open Universities in the United Kingdom and the Netherlands where it emerged as the "outreach model." Here, outreach is interpreted as "the provision of information or services to groups in society who might otherwise be neglected" (MSN Encarta, 2005). This model implies, then, that the university as repository of wisdom reaches out to those in need of knowledge and fills their empty jugs with the enchanting elixir of knowledge. This approach to improving the relationship between technical experts and the general public is illustrated in Figure 1.

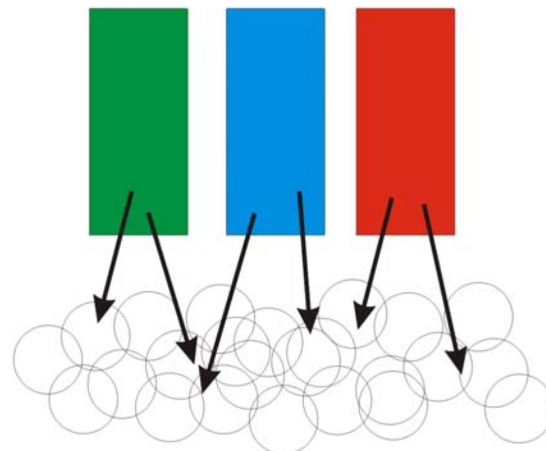

Figure 1 The outreach expert imparts scientific and technical knowledge to the general public.

Undoubtedly, the effective dissemination of technical knowledge is important to rebuilding trust between the techno-scientific community and the general public. However, the outreach-expert approach has significant shortcomings. First, it does little to address power differentials between experts and non-experts, and instead adheres to the "sage on the stage" model of modern scientific and technological development. It reinforces paternalistic, modernist modes of technological development. Thus, this approach can be seen as token reform because it solely emphasizes the need for the public to better understand technical expertise while leaving expert practice unchanged. Furthermore, it implies that the public, through its ignorance, is largely to blame for scientific and technical failures. The program of fostering outreach is also apt to exacerbate the divide between experts and non-experts. Suffice it to say, an increase in expert-knowledge dissemination is not *per se* a complete solution to tackling sustainability, but, done properly, can effectively communicate scientific and technical knowledge, a crucial component to resolving the tensions between expertise and sustainability.

The Interdisciplinary Expert

Another option for accommodating and aligning technical experts with the discursive, political nature of sustainable development is to increase the permeability of disciplinary boundaries. This proposition addresses the lack of communication among technical experts, colloquially referred to as the "disciplinary silo effect." Particularly in large universities, researchers from different disciplines address similar problems in parallel, rather than collaboratively, due to restrictive institutional and disciplinary norms.

One suggestion is to foster a more extensive general education program for technical experts, one that recognizes the overlaps between related disciplines and identifies strategies to transcend existing norms that discourage interdisciplinary work. This effect is illustrated in Figure 2 where the interdisciplinary expert blurs the boundaries between scientific and technical disciplines. The aim is not to abandon specialized technical knowledge, but rather to improve the experts' understanding of their roles with respect to other disciplines, particularly where commonalities exist. Undoubtedly, to truly realize interdisciplinary cooperation, multiple barriers need to be overcome, including but not limited to jargon, epistemological assumptions, funding protocols, and the portioning of reputational credit from joint projects. For example, the politics of "units of assessment" (UoA) of the UK research assessment exercise (RAE) creates disincentives to collaborate across disciplinary boundaries. The work of every researcher in the country has to be allocated to one of the 67 subject-based UoAs and critics argue that this mechanism poses problems for the practice of interdisciplinary research–although the responsible organization denies that this is the case (HERO, 2002).

Figure 2 The interdisciplinary expert blurs the boundaries between scientific and technical disciplines.

An example of the benefits of interdisciplinary cooperation can be seen in the Belgian city of Hasselt, located seventy kilometers east of Brussels. Severe traffic-related problems triggered an engineering proposal to build a third-ring road around Hasselt to divert traffic from its historic center. The city council, however, ignored the proposal and instead narrowed the traffic artery in the inner city, increased public-transport services eightfold, introduced a five-minute interval on select bus routes, built several miles of new bicycle lanes and guarded bicycle sheds, installed showers for cycling commuters, storage facilities for pedestrian shoppers, and heated waiting rooms for bus passengers, planted hundreds of trees along the main pedestrian-access routes, established bicycle pools in which adults volunteer to accompany children from their residential neighborhoods to school and granted a bicycle bonus to employees who cycle to work (see Brand, 2005a). In sum, the approach included "hard" infrastructure measures and "soft" solutions that, in combination, created a successful new transportation strategy on multiple levels. One of the people involved in designing these integrated solutions explicitly distinguishes the chosen strategy from the initial proposal. This respondent contended that the authors of the initial plan "made the mistake of only looking at the 'engineering' side of it…[For me] the success of the Hasselt project is all about a combination of measures, definitively not only by engineers: engineering, mentality, environment, city building, social issues, communication" (Moerkerk, 2002).

Similar to the previous notion of the outreach expert, the interdisciplinary expert has merit but again, fails to question the notion of a core element of expert knowledge–if the problem is not within one's own discipline, it at least should be within the confines of the alma mater. In other words, improved communication, understanding, and collaboration between disciplines do nothing to challenge the boundary between experts and non-experts.

The Meta-Expert

Taken to its extreme, the preceding notion of the *interdisciplinary expert* begins to resemble an entirely new class of expert that we label here the *meta-expert*. The role of the meta-expert is to juggle the sundries of multiple technical knowledges and, in effect, to act as a broker of expert knowledge. The meta-expert is a generalist with a clear understanding of what specific disciplines can and cannot contribute to problems of sustainability. Understood in this way, meta-experts have not only the license but also the remit to "pick cherries"–they are officially approved "eclecticists" who have the skill to translate across different clusters of expertise. We can graphically illustrate the meta-expert with a transverse beam across different disciplinary silos (see Figure 3).

Meta-experts adhere to the ontological assumption that sustainability is neither a "problem of simplicity" nor a "problem of disorganized complexity," but rather is a "problem of organized complexity" in the sense described by Jacobs (1961). Under the first assumption, cause-and-effect chains can be fully explained, and thus solved, by formulaic management rules; under the second, these chains are too complex to be fully described and can be tackled only with stochastic evaluations of previous interventions. In contrast, a problem of organized complexity consists of patterns that can be understood–albeit not by a sole individual. Instead, organized complexity necessi-

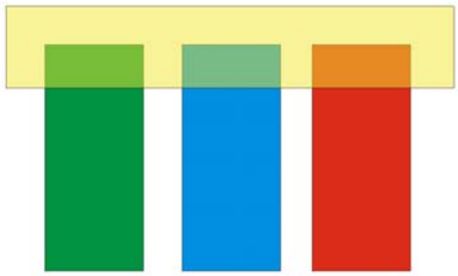

Figure 3 The meta-expert bridges scientific and technical disciplines

tates the pooling of understandings and knowledges to develop a shared asset base. It acknowledges that all types of experts are needed, as well as individuals who can weave these strands of thought together to construct the *whole*. This does not imply that the "weavers" know the *whole*, but they should be able to identify potential linkages and facilitate their co-discovery.

An example of the meta-expert can be found in sustainable building practices that have emerged in the United States, the United Kingdom, and Northern Europe during the past decade. The sustainable building expert juggles the multiple strategies of sustainable building (e.g., energy efficiency, materials selection, indoor air quality) to create a coherent set of interrelated goals for a particular project. Such an individual is not expected to have in-depth expertise in all the technical disciplines related to the project, but rather should understand the interrelationships among the different sustainable strategies and the overlapping responsibilities of each team member. In other words, the sustainable building expert recognizes that sustainability strategies are typically multivalent, with numerous implications for the project as a whole.

Other disciplines have also anticipated the need for meta-experts to manage sustainability activities and have perceived their members to be intimately qualified for this brokering position. Cliff Hague (1997), former president of the UK Royal Town Planning Institute, argues that planners are reasonably well equipped to play this role because "town planning…has [always] prioritized synthesis over analysis. Planners have been magpies across the disciplines, picking relevance where they found it." One could also imagine that public-policy experts, sociologists, anthropologists, and geographers would be particularly appropriate for such roles.

The Civic Expert

So far, our proposed renovations to the model of expertise are advantageous to its traditional counterpart because they increase communication and collaboration among experts or improve communication to non-experts. However, none of the models systematically challenges the privileged status of expert knowledge or attempts to engage in a substantive manner with non-experts. What is missing until this point is the idea of *listening* to so-called non-experts. Brand (2005b) describes such individuals who are familiar with everyday practice as "the ultimate experts in user behavior."

A fourth model we refer to as *civic expertise* entails listening to and engaging with citizens to take advantage of their experiential knowledge and to inform technological and scientific development (see Figure 4). Sclove (1992) notes that the participatory model of expertise highlights the social contingency in technological endeavors, elicits critical reflection on social circumstances and needs, and allows for the recognition of non-focal technological consequences. Schot & Rip (1996) refer to this process as "second-order learning" that involves critical reflection upon the assumptions that underpin the pursuit of factual and technical first-order learning. In other words, the involvement of citizens in the design of technologies can broaden the traditional expert approach by not only asking *how*, but also asking *why*. The model of *Mode 2 Science* as proposed by Gibbons et al. (1994) addresses this challenge of involving users as well as researchers through *trans*-disciplinary endeavors. Only through such participatory, discursive, and multifaceted approaches can science become "socially robust" and accountable (Nowotny, 1999). The civic-expertise model is therefore the point where practical considerations about the feasibility, acceptability, and efficacy of technological interventions for sustainable development converge with the normative call for the democratization of technology

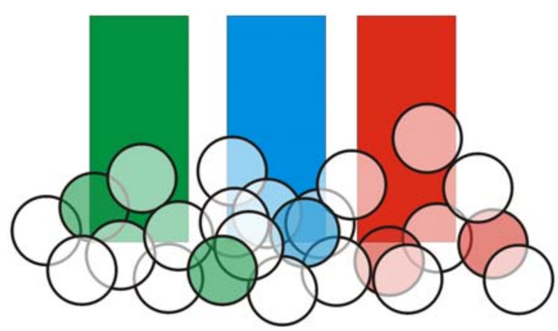

Figure 4 The civic expert encourages deliberation between experts and non-experts.

(see Sclove, 1995; Fischer, 2000). The civic expert relies on the notion that "the rules for [the] *production* of scientific knowledge will have to change in order to enact civic science" (Bäckstrand, 2003, emphasis added).

A number of promising techniques have been developed to foster deliberation between technical experts and the general public, including constructive technology assessment, strategic niche management, citizen panels, and the *L'Eprouvette* initiative at the University of Lausanne.[7] The intent of these experiments is to open policy-making procedures to actors other than technical experts by including citizen voices in scientific and technological debate (see Rip et al. 1995).

This discursive model of technological development is perhaps the most ambitious option due to ingrained power relations, a lack of commonplace practices, and inexperience at deliberation among all individuals, experts and non-experts alike. It is no coincidence that more democratic forms of technology development have emerged in political cultures such as Denmark, the Netherlands, and Germany that are sympathetic to the notion of increased citizen participation in political decision making. However, even in these countries, participatory technological policy making is an exception to the rule and their experiences highlight the challenges to expanding the number of voices in technological decision-making processes.

Democratic deliberation, in effect, requires that all participants, both experts and non-experts, take citizenship seriously because technologies constitute states and societies (Sclove, 1995; Barber, 2004). The ultimate benefit of the civic-expert model and increased input from non-experts is the potential for better decision making via the "intelligence of democracy" (Lindblom & Woodhouse, 1993). Searching for agreement among multiple stakeholders allows consideration of diverse opinions and extends the simple notion that "two heads are better than one." This makes the civic expert uniquely suited to tackle what we described above as a practical problem of conventional forms of expertise, the "stochastic effect of harnessing the creativity of thousands of individuals." As such, the civic expert recognizes the polyvalent nature of technologies and enlists all stakeholders in the process of characterizing and considering a technology's social implications (Sclove, 1992).

Conclusion: Synthesis of the Expert Models

What, then, should we tell our students who ask for advice on becoming sustainability experts? Should we portray their career goals as a *sui generis* new role in yet untouched areas of the social, cultural, technical, political, and academic landscape? Alternatively, should we mumble something about the concept of the "sustainability expert" being an oxymoron and, instead, encourage them to learn as much as possible of what their respective disciplines have to offer to discourses on sustainability? Or should we urge them to "pick cherries" of relevance wherever they find them, irrespective of their disciplinary allegiance? We believe that it would be best to present the idea of an *ecosystem of expertise* where different niches need to be filled–and no one can fill all of them. The goal is to define our individual roles in ways that take advantage of our strengths and, thus, we have to train and encourage our students to find and vitalize their individual niches.

None of the above models alone is sufficient to tackle simultaneously the ontological and epistemological problems, the power issues and practical difficulties regarding expertise and sustainability. But there are clear merits in each approach. We argue that the most viable way forward is to attempt to embrace all of the models, as illustrated in Figure 5. The importance is not in determining which approach to expertise is most effective at creating more sustainable societies, but rather how each of us can best orient our work towards one or more of these models.

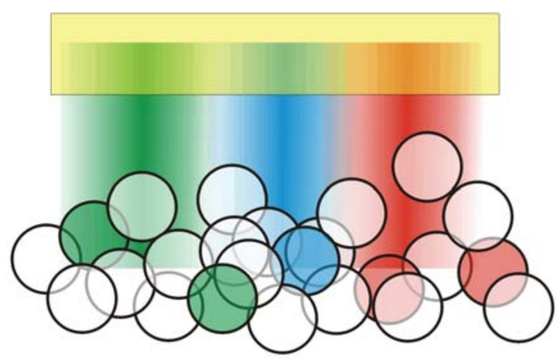

Figure 5 The ecosystem of expertise.

However, we would like to issue two general pieces of advice to anyone who intends to play a role in the ecosystem of sustainability expertise, regardless of which niche he or she inhabits. First, it is important to maintain a bird's-eye view on the whole system and to resist the temptation of adopting old (or new) exclusivity claims. Only if we are aware of the importance of different niches will we appreciate

[7] See Labo "L'Eprouvette" at http://www.unil.ch/interface/

and seek strategic collaborations with them and respond productively to their invitations. The second piece of advice is to lobby for the dissolution, or at least the lowering, of institutional barriers that inhibit multi- and trans-disciplinary collaboration. The first point is an individual agenda, the second a political one.

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ARTICLE

Challenging knowledge hierarchies: working toward sustainable development in Sri Lanka's energy sector

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This paper analyzes sustainable development practices within Sri Lanka's energy sector. It directs attention to how expertise functions in development decision making in ways that can unintentionally inhibit sustainable development. Understanding expertise as merely specialized knowledge clouds its role as a social activity. In practice, expertise is a combination of knowledge and authority, and expert knowledge exists within a hierarchically ordered authority structure of diverse knowledge domains—what is referred to here as "knowledge hierarchies." Knowledge hierarchies exclude the participation of some relevant knowledge domains, and thereby preclude the possibility of local sustainable development. The Energy Forum of Sri Lanka, a small renewable energy advocacy organization, strives to enable sustainability by going beyond facile calls for greater inclusion to confront the mechanisms of exclusion. The paper documents three of the Energy Forum's development interventions intended to level out the knowledge hierarchy that inhibits sustainable energy development in Sri Lanka. Drawing insights from the Energy Forum's approach, the paper argues that experts who wish to contribute to sustainable development must attend to the knowledge hierarchies in which they operate to ensure that their own authority does not exclude other relevant knowledge domains.

KEYWORDS: sustainable development, energy resources, decision models, social behavior, indigenous knowledge, renewable energy resources, nongovernmental organization

Introduction: Rethinking Development, Rethinking Expertise

The importance of sustainable development is clear. Global ecological change, increasing inequities in wealth and access to resources, and the dismantling of social and cultural "safety nets" provide good reasons for caring about and working toward sustainability. The role of expertise in sustainable development, however, is not so clear. Surely, achieving sustainability requires robust expert knowledge in diverse domains: ecology, biology, environmental monitoring, national and global policy, development economics, and many others. Much scholarly attention has been devoted to identifying and developing these knowledge domains in the service of sustainability. Far less attention has been given to empirical study of expert practices directed toward sustainability and the larger social contexts in which those practices have meaning. Based on ethnographic fieldwork among Sri Lanka's renewable energy community, this paper shows that the role of expertise in development practice is multifaceted, with some facets contradicting what we typically understand as the experts' role.

Before scrutinizing expert practices in Sri Lanka, though, it is important to clarify and contextualize the paper's key concepts: sustainable development and expertise. "Sustainable development" means different things to different people, but two distinct common usages prevail (Smillie, 2000). In the United States, and perhaps much of the North, the majority of people associate sustainable development with efforts to align goods and services provision with ecological protection, so that biological systems can remain or become healthy while human societies construct higher living standards.[1] Here, sustainable development means economic or material (infrastructure, technology, consumer goods, built environment) gains that are ecologically sustainable in terms of resource extraction, waste production, and long-term ecosystem health. For many development workers, however, sustainable development has a different meaning. It refers primarily to the ability of development initiatives to subsist over time, especially after external development funds and expertise are withdrawn. Ecological sustainability is part of the equation here, since local environmental decay would

[1] Following current trends in development scholarship, I use the shorthand "North" and "South" to distinguish between economically wealthier and poorer countries, respectively. Within this terminology, Australia and New Zealand are understood to be economically (as well as culturally) integrated among the economically powerful countries in the global North.

eventually undermine development projects. However, ecological sustainability is only a part of the equation, and typically not the most central part, at least among development project planners. More central are financial sustainability, community-level skills creation (or "capacity building" in the development jargon), awareness raising and community investment, and ongoing project management, typically through local organizational support. The ecological and project sustainability discourses are not mutually exclusive, of course, and examples of each exist in both the North and South despite the rift between their dominant uses in each context. Nevertheless, this paper relies primarily on the latter understanding of sustainable development, because it directs attention to a broader spectrum of relevant expert knowledge.

Sustainable development in this sense is the latest in a long series of efforts to rethink "development" and how it ought to best be pursued. The need for rethinking has been stimulated, in part, by a long history of disappointing results (Rist, 1997). Focusing on *sustainability* adds something new to development thinking, both in terms of attention to facets of the development equation beyond technological and institutional infrastructure and in terms of the knowledge base necessary to design more robust interventions (Van der Ryn & Cowan, 1996; McLennan, 2004; Willard & Andjelkovic, 2005). Like much prior thinking, however, the idea of sustainable development falls prey to problematic assumptions about how development occurs, or why it fails to occur. Like dominant development thinking—that is, the way most people understand the development problem—much of the work on sustainable development is based on a deficiency model, where lack of adequate material or knowledge resources are understood to cause underdevelopment (Escobar, 1995). Development is to be stimulated, according to this model, by injecting the missing resources. In this way, sustainable development calls for a broader set of knowledge resources than traditional development, but the role played by development experts is roughly equivalent (see, e.g., UNDESA, 2002).

The deficiency model of underdevelopment has several important shortcomings, not the least its misattribution of symptoms as causes. Rather than causing underdevelopment, lack of adequate resources is a symptom of deeper structural problems (Escobar, 1995; Rist, 1997). Even if underdevelopment is defined as (as opposed to being caused by) lack of material and knowledge resources, that says little about whether resolving such deficiencies at a specific time will result in *sustainable* development solutions. "Dependency theory" goes further to argue that provision of development assistance fosters dependence on donors and thereby impedes development efforts.[2]

Rejecting the assumption that resource deficiencies are the primary cause of underdevelopment has important implications for analyzing the role of expertise in sustainable development. If underdevelopment is merely a problem of deficient resources, then knowledge and financial resources could easily be added to fill the void. If the problem is not merely deficient resources, then the role played by expertise must be more complicated than simply providing those resources. Thus, in rejecting the deficiency model of underdevelopment, we must also challenge assumptions about expertise (Woodhouse & Nieusma, 1997). Certainly, designing sustainable development interventions requires contributions by diverse domains of expert knowledge. However, "expertise" is more than the knowledge embodied within individuals. Expertise is a whole set of *social practices* that entail complexities glossed over in typical understandings of expertise as individualized knowledge (Bereiter & Scardamalia, 1993; Hutchins, 1995; Agre & Schuler, 1997). Most importantly for this analysis, expertise functions not only through knowledge transfer, but also as a strategic resource in struggles surrounding decision-making authority (Fischer, 1990; Frankena, 1992; Epstein, 1996; Martin, 1996). Because it is a social practice, it is important to approach the analysis of expertise in sustainable development with attention to social power (Fortun, 2001; Woodhouse & Nieusma, 2001; Nieusma, 2004).

Thus, achieving sustainable development requires moving beyond the deficiency model of underdevelopment and rethinking the role played by expertise in development practice (Brand & Karvonen, 2007). Rather than thinking of expertise merely as specialized knowledge added to the development mix, this article employs a practice-based definition: *expertise is specialized knowledge combined with authority*. By understanding expertise as "knowledge plus authority," we are better able to see that knowledge domains needed for sustainable development are not simply absent, but are systematically excluded, and that expertise is implicated in that exclusion (Kothari, 2001). In this way, misconceptions surrounding expertise—specifically the tendency to equate expertise with specialized knowledge—undermine efforts to rethink the "development problem" and make it impossible to achieve sustainable development. Only by understanding how ex-

[2] Dependency theory has been widely discussed and has different variations, including notably Frank's (1967) macro-level Marxian treatment. For an accessible introduction to dependency theory, see Ferraro, 1996. Harvey & Lind (2005) provide a recent review and critique of the dependency thesis.

pertise functions to exclude relevant knowledge domains in development decision making can we devise strategies for countering it and thereby hope to achieve sustainable development.

To make this argument, the next section introduces Sri Lanka's energy context and highlights the importance of knowledge authority structures—what are called "knowledge hierarchies"—to expert decision making in that context. Next, I focus on one organization, the Energy Forum, and its efforts to institutionalize sustainable development in Sri Lanka's energy sector. By describing three specific intervention strategies, this discussion shows how the Energy Forum sought to systematically empower marginalized social groups and bolster the authority of their knowledge vis-à-vis established experts. I then analyze the Energy Forum's strategies as interventions into knowledge hierarchies, or, in other words, as the *renegotiation of expertise* in that context. Finally, the concluding section reflects on the importance of reconceptualizing expertise to contribute most effectively to sustainable development practices.

Knowledge Hierarchies in Sri Lanka's Energy Sector

To contextualize my analysis, this section turns to Sri Lanka's energy sector, challenges to sustainable development practices in that context, and the role played by expertise.[3] A tropical island located off the southern tip of India, Sri Lanka has a population of just over 19 million people and enjoys higher than regional averages in health, education, and economic indicators. Ranking 93 in the United Nations Development Programme's 2005 Human Development Index, Sri Lanka is situated in the middle of the "medium human development" category, with life expectancy at birth of 74 years, adult literacy rates above 90% (89% for females and 92% for males), and gross domestic product (GDP) per capita of US$948 (purchasing price parity US$3778) (UNDP, 2005). The nation's ethnic makeup is roughly 74% Sinhalese, 18% Tamil, and 7% "Sri Lankan Moors," which overlaps considerably with its religious makeup: 70% Buddhist, 15% Hindu, 7.5% Muslim, and 7.5% Christian (half of Sinhalese and half of Tamil ethnic heritage). The vast majority of Sri Lankans live in rural settings, with only 22% of the population in urban areas. Sri Lanka's mountainous geography combines with tropical rainfall to create an ideal setting for hydropower which provides over two-thirds of the nation's 1,500MW generation capacity, with the majority of the remainder coming from fossil fuel-fired thermal generation (CEB, 1999).

Sri Lanka's energy setting is particularly relevant for investigating the role of expertise in development due in part to two challenges facing the country. First, electricity-supply deficiencies have plagued Sri Lanka since the 1980s, resulting in substantial power cuts across the nation for months on end. Due to heavy reliance on hydropower, energy-supply shortages are exacerbated during periods of drought. These shortages—recurrently dubbed "the energy crisis"—capture national attention and, at their peaks (1995–1996 and 2001–2002), were among Sri Lanka's most divisive political issues, surpassing even the 20-plus-year civil conflict in terms of attention from politicians and the media. Power cuts are administered by the national electricity monopoly, the Ceylon Electricity Board (CEB), as rolling, scheduled—and frequently unscheduled—blackouts, where power is cut for entire regions of the country for hours at a time. While larger businesses and wealthy residents have installed private generators, the majority of the population goes without electricity during power cuts. At the peak of the 2001–2002 power crisis, electricity was cut to the entire city of Colombo for up to six hours per day—three hours during the day and three hours in the evening.

The second, related challenge is that of rural electrification. While electricity shortages occupy newspaper headlines for months on end, advocates of Sri Lanka's rural poor agitate for greater attention to "the other side of the energy crisis." Over two million households, comprising almost 50% of the country's population, lie beyond reach of grid electricity altogether. Despite an impressive ascent in rural electrification rates over the past few decades, grid extensions to remote regions are costly and further exacerbate the electricity-supply deficiency. Without access to grid electricity, "off grid" households either do without power or rely on costly alternatives: kerosene lanterns for lighting and, for the better off, automobile batteries (charged in the nearest grid-connected town) for radio and television.

In response to these energy "crises," a relatively cohesive (if frequently contentious) community of energy and development experts coalesced and it was among these individuals that my research on energy and development expertise in Sri Lanka was conducted.[4] Well developed in both breadth and depth, Sri Lanka's energy community is populated by

[3] Portions of this section are taken from my dissertation (Nieusma, 2004).

[4] My research in Sri Lanka consisted of 11 months of participant-observation, dozens of interviews, and media coverage analysis in 2000 (supported by the US National Science Foundation) and 2001–2002 (supported by the US-Sri Lanka Fulbright Commission).

Table 1 Major Organizations in Sri Lanka's Energy Sector.

Sector	Organization	Expert Knowledge Domains
Government of Sri Lanka	Ministry of Power & Energy	Oversight of state-owned energy agencies; energy policy making
	Ceylon Electricity Board (CEB)	Nationwide electricity-systems operation; least-cost energy systems modeling; large-scale hydro and thermal energy technology
	Alternative Energy Unit, Ministry of Science & Technology (MoST)	Energy-systems modeling and R&D; sustainable biomass agriculture; dendro technology
	National Engineering R&D Centre	Appropriate technology R&D; renewable energy technologies
	Ministry of the Environment	Environmental protection and policy; carbon trading
	Provincial Councils	Provincial energy policy; rural electrification
Private-Sector Organizations	Shell Renewables	Solar home-system financing and sales; sales office-network extensions
	Solar Electric Light Company	Solar home-system financing and sales; sales office-network extensions
	Lanka Electric	Electricity generation for grid connections
	Independent hydro power developers	Off-grid and grid-connected small-scale hydro systems design and implementation
	Solar Industries Association	Solar energy technology R&D, sales, and financing; lobbying of policy makers
	Bio Energy Association of Sri Lanka	Biomass energy R&D, finance, agriculture, and technology; lobbying of policy makers
Non-Governmental Organizations	Intermediate Technology Development Group, South Asia (ITDG-SA)	Appropriate technology R&D; technology-based development planning; rural development
	Energy Forum	Renewable energy technology and policy; grassroots-awareness raising; rural development
	Electricity Consumer Societies	Off-grid energy systems operation and maintenance
	Community-based development organizations	Rural development design and assessment; miscellaneous foci
International Development Organizations	World Bank (Renewable Energy Program Teams)	Energy-program finance; energy markets; renewable energy technologies
	Asian Development Bank (ADB)	Infrastructure-program finance

organizations and prominent individuals representing the three major social sectors—public, private, and civil society—as well as international development organizations (occupying hybrid positions). Table 1 lists the most prominent organizations that make up Sri Lanka's energy sector, with a focus on those entities working with renewable energy technologies or rural development. Table 1 also identifies each organization's primary domains of expert knowledge.

The diversity of organizational players provides undeniable strengths to Sri Lanka's energy sector. In spheres as complex as development planning, input from diverse knowledge domains is needed for informed decision making. Indeed, despite limited success in attaining development goals, five decades of intervention have led to more complex development initiatives that draw on a wider range of experiences, going beyond scientific, technical, and financial expertise to include cultural knowledge (Sen, 2004) and an understanding of the limits of technology-based aid (Willoughby, 1990). The widely touted, if loosely conceptualized, "integrated development" approach attempts to bring together such experts in development planning.[5] Furthermore, advocates of alternative development paradigms emphasize the need to include diverse "local knowledge" domains in addition to recognized expert knowledge. "Local knowledge" refers to knowledge domains relevant to specific contexts of project implementation and their environmental, cultural, political, and organizational peculiarities (Antweiler, 1998). This includes experiential knowledge at the same level as the decision being made—for example, national, provincial, and community—each with its own idiosyncrasies. It also includes local adaptations of "expert" knowledge, where generalized disciplinary knowledge is made meaningful within local

[5] "Integrated rural development" strategies were popular during the 1970s and then fell out of favor after about a decade (Smillie, 2000). Still, the general idea of integrated development has remained in circulation, including among development workers in Sri Lanka. A contemporary example of an integrated development strategy is the World Bank's cross-sectoral initiatives that attempt to connect various projects and experts, in sectors as diverse as healthcare, education, infrastructure, and rural economic development.

worldviews.[6] Problems arising from the failure to account for context-specific circumstances have been well theorized and documented since at least the early 1970s (Schumacher, 1973; Chambers, 1983; Papanek, 1984; Smillie, 2000).[7]

The fact that numerous organizations with diverse interests and wide-ranging expertise populate Sri Lanka's energy setting, however, does not ease energy development decision making within the community. Intense negotiations occur among experts with competing notions of what is required for successful development, and sometimes with radically divergent definitions of development itself. In the course of research, these negotiations provoked questions such as: Is grid electrification a prerequisite for rural economic development, or does it encourage passivity and dependence? Should the design of development programs start from sound financial planning or experienced community needs? Can development projects be deemed successful simply by electrifying households, or are improved social and economic indicators also necessary? Such questions were debated in numerous settings across Sri Lanka. While the substance of these negotiations was interesting, my concern here is only with the processes by which they occurred. In particular, the following discussion will explore how knowledge and authority mapped onto expert practices in this context: Which forms of knowledge were included in or excluded from sustainable development decision-making processes? How were such determinations made? And how were they resisted?

One important determinant of authority in Sri Lanka's energy sector is organizational power. Not surprisingly, powerful entities enjoy greater authority in development decision making than weaker organizations or unorganized groups. Yet even the most authoritative do not rely on power alone in coming to decisions; they do not simply disregard their critics out of hand. Instead, the most institutionally powerful players justify development decisions by appealing to the expert knowledge under their command. During my research, for instance, the World Bank, arguably the most powerful player in Sri Lanka's energy sector, typically justified its decisions by appealing to the authority of two domains of knowledge: project finance and market economics. Regardless of a proposed development project's overall merits, if it did not fit the World Bank's finance-based development approach, it was rejected on that count. Hence, organizational power combines with the authority of expertise to set the terms of debate in Sri Lanka's energy sector.

Groups that reject the World Bank's prioritization of financial indicators still must learn to use the language of project finance, market creation, and income generation if their voices are to be heard among the most powerful development project decision makers. In this way, decision making in Sri Lanka facilitates participation by those groups with the corresponding expert knowledge—those fluent in the dominant discourse. At the same time, it discourages participation by groups not conversant in the dominant discourse—those without the expert knowledge valued by authority structures. Figure 1 illustrates, in a loose hierarchy of authority, diverse organizations populating Sri Lanka's energy community. The figure also includes diverse knowledge domains surrounding energy and development projects in that hierarchy and draws connections between the different organizations and the knowledge domains best represented within them. The term "knowledge hierarchy" refers to the authority structure of different knowledge domains, as represented in the left-hand column. In Sri Lanka's energy community, the knowledge domains of market economics and project finance have greater authority than, for instance,

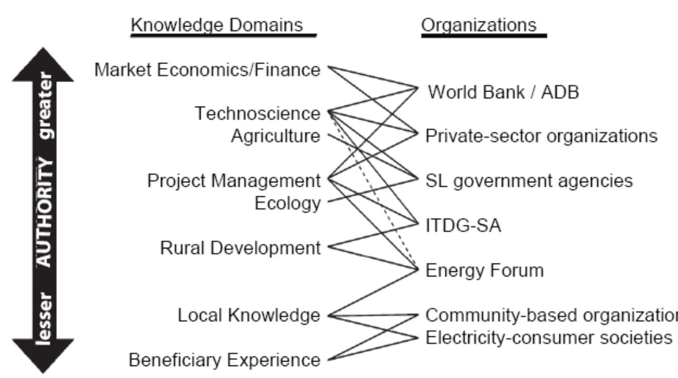

Figure 1 Knowledge and Organizational Authority Hierarchies in Sri Lanka

[6] Scholars in science and technology studies have shown that all knowledge is an integral part of the specific worldviews in which it functions (Haraway, 1991; Restivo, 1994). No group brings pure knowledge divorced from the worldview that gives it meaning. Thus, as knowledge, even technical knowledge, is created within or moves between cultural groups, it is adapted to fit within those groups' worldviews (Eglash, 2004). This insight has particular importance for how we conceptualize "local knowledge." In an important respect, all knowledge is "local" in terms of being situated in a particular context. While Colombo is Sri Lanka's "national" decision-making setting, the knowledge that circulates in Colombo is no more national than that which circulates in rural villages. Colombo knowledge does not encompass the knowledge of rural localities in the same way as a nation encompasses its hinterlands.

[7] One could reasonably argue that the appropriate technology movement's most enduring contribution to development thinking is that "context matters," that context-specific knowledge is crucial to development planning and project implementation (Willoughby, 1990).

those of ecology and rural development. Beneficiary experience tends to have strictly limited relative authority. The figure does not suggest a causal relationship, but does show a clear correlation between organizational power and the authority of knowledge domains held within organizations.

This knowledge hierarchy is neither formal nor fixed. Relative positions change slightly over time, across context, and by issue. However, the overall configuration, and the connections between authoritative knowledge and organizational power, endures. Participants positioned lower in the hierarchies are not denied the "right" to have a say in development planning by virtue of their social standing or otherwise, but the perspectives of those individuals who represent less authoritative knowledge domains (or organizations) are simply trumped in decision making by those with greater authority.

As a brief example, let us consider a development project aimed at disseminating solar home systems in rural Sri Lanka. Community-level expertise with regard to the effectiveness of this project in meeting rural development goals—such as increased economic security, higher education achievements, and initiation of entrepreneurial activity—was neither denied legitimacy nor publicly devalued by the most powerful decision makers. To the contrary, its legitimacy was affirmed. Yet, in the relevant decision-making settings, it was nevertheless considered less important than the financial solvency of the development program itself. Rural development expertise simply did not overrule financial concerns affecting development planning.

Organizations with expert knowledge in domains lower in the hierarchy struggle to find ways to inject their perspectives into development planning, working within the dominant discourse to be heard while simultaneously challenging basic assumptions of that discourse. One such organization is the Energy Forum, a small non-governmental organization staffed and directed by six engineers and experts in community organizing and awareness raising. It works closely with project implementers and development workers representing a variety of disciplines. It also has exceptionally strong ties to local knowledge "experts" at many levels: Sri Lankan energy policy makers, regional environmentalists, provincial government functionaries, and community-based organizations across rural Sri Lanka. The Energy Forum employs a roundabout strategy for bringing marginalized expertise to the decision-making table. Rather than confronting the legitimacy of organizational power imbalances in Sri Lanka—a strategically "unmentionable" topic—the Energy Forum challenges the legitimacy of the given expert knowledge authority structure. Instead of confronting institutional power inequalities head on, which most certainly would be a losing battle, the Energy Forum targets the knowledge hierarchy itself. In so doing, it seeks to put "experts" of various stripes on more equal footing, both in numerous local contexts and across the nation's energy and development community.

The Energy Forum's Three Development Interventions

In part because of its competing missions, the Energy Forum occupies an interesting place in Sri Lanka's alternative energy community (see Figure 2). As a "forum" for Sri Lanka's energy sector the organization's first mission is to facilitate communication and cooperation among sometimes-competing energy-sector interest groups. In this role, the Energy Forum's leadership seeks to maintain the organization as a nonpartisan "network hub" by not taking sides but by facilitating dialogue in energy controversies. The organization's second mission, however, is to advocate specific types of solutions to energy and development problems. Of course, advocacy entails partisanship which conflicts with the first mission. Additionally, this second mission has its own internal tension, namely, that between endorsing specific alternative energy technologies and promoting the interests of the rural poor, especially through rural electrification.[8] Members of the Energy Forum recognize that, although these two goals are often aligned, alternative energy technologies and the interests of rural villagers are not always compatible.

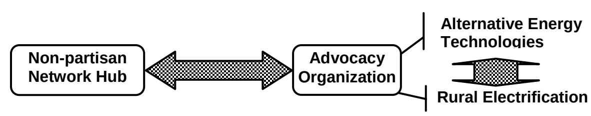

Figure 2 Tensions in Energy Forum's organizational missions

The Energy Forum's efforts to negotiate the tensions surrounding its multiple organizational missions parallel its work to reconcile a host of sometimes aligning, sometimes competing external interests and expertise surrounding energy and development in Sri Lanka. To provide a concrete sense of the organization's approach, the following subsections will describe three specific activities: interest-group organizing, consensus meetings, and organizational networking. Each of these activities captures the Energy Forum's implicit strategy of renegotiating the

[8] The Energy Forum promoted "renewable, decentralized energy options," such as small-scale hydro, solar photovoltaic, solar thermal, wind, and bio-energy. My shorthand "alternative energy technologies" encompasses these various systems.

role of expert knowledge in development decision making.

Interest-group Organizing

The first strategy employed by the Energy Forum to achieve its organizational missions has been interest-group organizing. Many players within Sri Lanka's energy community are poorly organized or totally unorganized, and many established development organizations work to coordinate a variety of interest groups in a number of contexts. Energy-sector development organizations seek to engage with rural communities for different reasons. One reason is the widely held belief that establishing formal organizational structures in beneficiary communities is needed to coordinate grassroots-development activities and to institutionalize responsibilities surrounding electrification-development initiatives. For example, if local community leaders are enrolled to promote solar-home systems or to collect loan repayments from community members who purchase such systems, it greatly facilitates the ability of rural electrification projects to meet their administrative and financial objectives. Likewise, if villages with micro-hydro facilities could effectively manage their own energy systems, rather than having them administered from distant Colombo, these projects could also more easily meet their goals.

In this vein, the Energy Forum organized several electricity consumer societies (ECSs) within villages that hosted alternative energy development projects. ECSs were initially launched in remote mountain villages with micro-hydro power plants. This was undertaken in part because such systems require careful monitoring (so that appliances such as irons, immersion water heaters, and refrigerators do not cause overloads), but also because a formal institutional structure is required for on-going management of project financing, systems operation, and plant maintenance. Almost everyone in Sri Lanka agrees that grassroots community organizations facilitate the administration of development projects and, therefore, are important determinants of project "success."

Most development workers recognize that strong community organizations benefit development projects by facilitating their administration. However, rural community advocates like the Energy Forum prioritize community organizing for a different reason, namely, because of its potential to promote learning and consolidate political power within rural communities, making them more effective in negotiating with external development decision makers. Community organization promotes learning by creating focal points for the interaction of residents and local skills-building initiatives. By consolidating political power within communities this kind of participation creates the potential to reverse the flow of information and, hence, development "knowledge." The Energy Forum's staff believes that for any group to have a voice in development decision making, even an indirect one, that entity needs to be cohesively organized so that powerful external groups do not advance their own interests by playing one community group against another. Rural communities without formal organizations cannot effectively represent their interests to government officials or external development agencies. The Energy Forum worked directly with many rural communities and local organizations across Sri Lanka and it often attempted to represent their interests in development planning meetings. At times, the Energy Forum was partially effective in speaking on behalf of rural communities, but its staff members believed they could only do so imperfectly, in a manner different from those groups speaking for themselves.

While ECSs effectively operated in dozens of villages across Sri Lanka as of 2002, the remoteness of the villages and the lack of communication channels meant that most of them could not share their experiences or coordinate their activities. Poor interaction among ECSs also meant that even official ECS representatives could speak authoritatively only on behalf of individual villages. For instance, when ECS representatives criticized specific policies or practices surrounding development programs, national decision makers easily dismissed those criticisms as anecdotal, "non-expert," or otherwise not characteristic of systemic shortcomings. To foster greater collaboration among ECSs and to bolster their authority the Energy Forum sought to take their organization to the next level. Working together with all of the individual societies, the Energy Forum helped to create a formal meta-organization, the Federation of Electricity Consumer Societies (FECSs). This meta-organization, the Energy Forum hoped, would not only encourage mutual learning among individual societies but also provide a powerful voice for communicating shared concerns to development program decision makers.

As this initiative illustrates, the Energy Forum seeks to create strong, cohesive organizations that can provide a vehicle for rural communities to present for themselves their experiences and understandings, allowing them to initiate communication flows that move up the development chain of command instead of always remaining only on the receiving end. By coordinating interest groups within and between rural communities, and by creating organizations to communicate rural perspectives to national decision makers, the Energy Forum has sought to increase the authority of rural community representatives vis-à-vis recognized development experts in Colombo's highly organized institutions.

Consensus Meetings

A second strategy employed by the Energy Forum has been the "consensus meeting." In Sri Lanka's national energy sector, certain groups are mired in highly contentious disputes over energy planning: community-development experts struggle with least-cost economists, socialist Provincial Council ministers struggle with World Bank program managers, and environmentalists struggle with coal-power advocates. Although all these groups are represented by what most participants would concede are, in fact, "experts," there are significant differences in their authority. The Energy Forum's consensus meetings brought together these "competing" experts to counter the divisiveness that inhibits development planning surrounding energy and electrification.

Through its consensus-building approach, the Energy Forum does not intend to eliminate substantive disagreement, but to catalyze constructive dialogue and mend strained relations among entrenched positions. For example, in bringing together CEB officials with representatives of environmental groups the Energy Forum did not expect to resolve a decades-long debate over the future of coal power in Sri Lanka. This debate has forced the CEB to conduct site and environmental impact assessments for one proposed plant location after another, costing the CEB, and hence the nation, millions of dollars. The controversy also allows the CEB to place responsibility for deficiencies in the country's electricity supply squarely, though undeservedly, on the shoulders of the environmental lobby. Especially in the nation's newspapers, the debate between the two sides of the coal-power option is deeply divisive and, for the most part, unproductive. Similarly, though with less derision or fanfare, Provincial Council socialists clash with the World Bank over the appropriate role of government in rural electrification, with the former advocating a central role for government and the latter striving to eliminate, insofar as possible, government agencies from the implementation of development projects. Community development experts advocating decentralized technologies clash with least-cost energy planners advocating centralized coal power.

Rather than expecting to resolve these deep-seated disagreements or to equalize the considerable institutional power imbalances, the Energy Forum used its consensus meetings to subtly but significantly shift the discourse surrounding these issues. The consensus meetings achieved this goal by creating a balanced conversation among experts representing radically different positions of institutional authority. The Energy Forum adopted the position of "neutral mediator" by laying out the ground rules for the discussion and moderating interactions to ensure that those rules were followed. It otherwise played a minimal role. The agendas for these meetings gave equal time to each side to present and respond, followed by a carefully moderated open discussion in which the Energy Forum did not take sides, explicitly or otherwise. Nevertheless, the very act of putting experts with different kinds and levels of institutional authority together as equals increased the less authoritative groups' legitimacy.

Since the Energy Forum's aim with the consensus meetings was to achieve agreement in terms of *procedure*, not necessarily in terms of substantive outcomes, participants were expected to agree on the importance of "hearing out" opposing perspectives. They were also expected to identify both where and why they disagreed and where and why they agreed. To be sure, creating procedural consensus in the face of ideological disagreement fueled by organizational power imbalances was no trivial achievement; the Energy Forum expended significant social capital and achieved modest results. But here again, as with organizing the FECSs, something more was at stake: systematically empowering institutionally marginalized groups and increasing the relative authority of their expert knowledge. Whereas the Federation empowered rural community members vis-à-vis Colombo experts, the consensus meetings empowered one group of experts relative to another.

Organizational Networking

A third strategy employed by the Energy Forum has been organizational networking. The prior strategies discussed—interest group organizing and consensus meetings—are two among many ground-level activities that the Energy Forum has sought to integrate into a larger networking initiative. This larger initiative is intended to achieve systematic, fair, and well-informed energy decision making in Sri Lanka. In particular, the Energy Forum has sought to institutionalize a comprehensive approach to empowering marginalized groups through the creation of what it called the "National Energy Network." As with consensus meetings and interest-group organizing, the Energy Forum had both modest, practical goals and grand ambitions for the National Energy Network. Practical goals included identifying and initiating strategic linkages between a host of previously unconnected organizations or interest groups, especially among different levels of the network. More ambitiously, the Energy Forum sought explicitly and systematically to bring more diverse interests and knowledge domains into the nation's energy-planning and decision-making processes. For example, the network included organizations from all three social sectors—public, private, and civil society—as well as

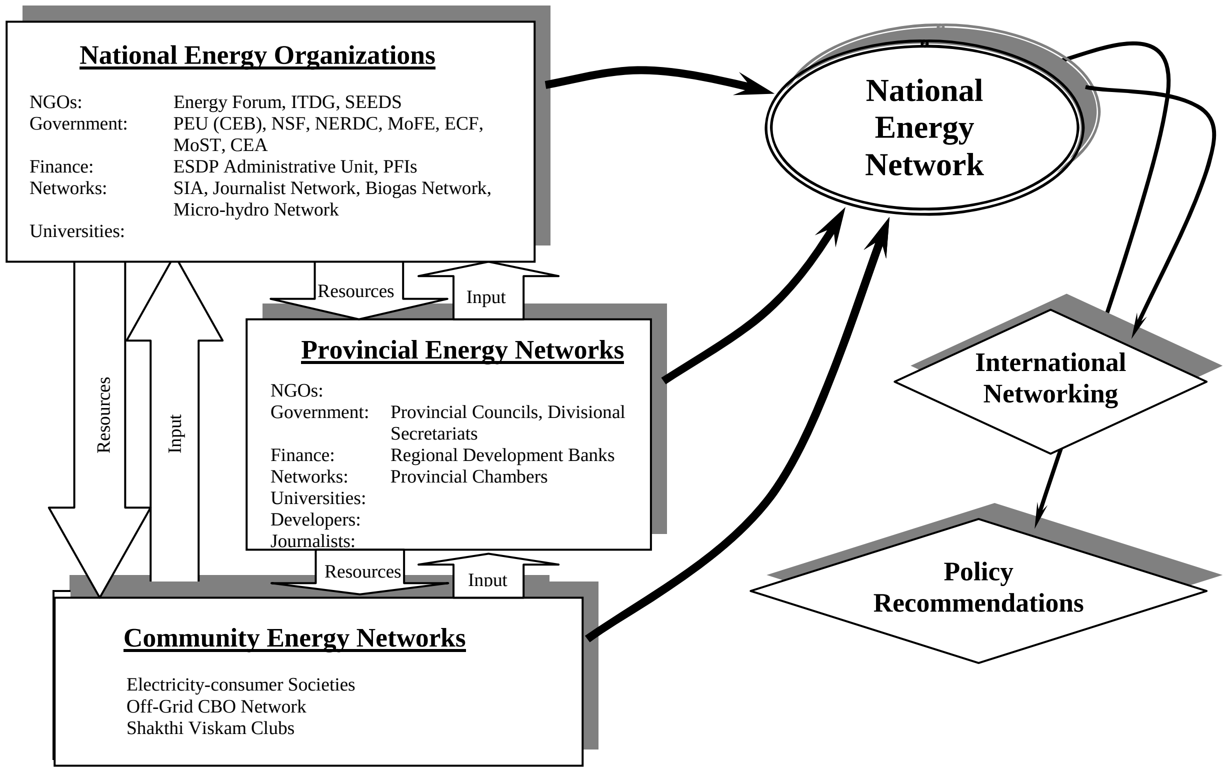

Figure 3 The Energy Forum's National Energy Network schematic (see appendix for acronyms).

from all three levels of government—national, provincial, and community. The National Energy Network was envisioned as a path to sustainable development through "strongly democratic" energy decision making.[9]

The Energy Forum's conceptualization of the National Energy Network is illustrated in Figure 3. Despite the top-down representation of the national, provincial, and community levels in the figure, the individual arrows linking each level to the national network are intended to communicate that each is to have equal input. Similarly, input is to flow up, from communities to national organizations, and resources are to flow down. The Energy Forum's coordinator intended this depiction to show how all energy policies should be directed to local community development needs rather than to solidifying the positions of authority of national or provincial organizations vis-à-vis other interests. In other words, the Energy Forum believed that while national-level organizations should provide the financial and technological resources needed by local communities, the communities themselves should have a say in determining how those resources ultimately would be directed, based both on their priorities and on their knowledge about what is workable within their specific local contexts. Once again, we see a strategy to renegotiate the authority of different knowledge domains. One might even say that "expert" knowledge is involved in both flows: "how-to" knowledge as a resource flowing down and "what can work" knowledge flowing up.

According to the Energy Forum, the National Energy Network schematic also communicates something important about where "global" perspectives are to fit. The "international networking" diamond exists outside of the national network, indicating that it is Sri Lanka's prerogative to determine its energy-policy directions and development goals and not that of the international agencies that provide development assistance. In the Energy Forum's version of a *national* energy network, Sri Lankan decision makers would first determine the nation's energy and development goals and then proactively "network" with international players for assistance to achieve those goals. Here again, strategic planning

[9] Benjamin Barber (1984) defines "strong democracy" as broad-based citizen participation in governance and elaborates how such participation contributes simultaneously to better decisions and participant edification. Sclove (1995) extends the application of Barber's concept from ordinary political contexts to technology design and implementation. Using the language of democratic deliberation, Fischer (2000) makes a similar argument in the context of environmental decision making.

input flows "up" to international agencies and resources flow "down" to increasingly local contexts: national, provincial, and rural community.

As conceptualized and represented, the National Energy Network embodies a powerful criticism of dominant development practice where external organizations determine development priorities (based on their own assessments of what is desirable and possible) and then create financial incentive structures for Sri Lankan organizations to achieve those priorities. With its conceptualization of the National Energy Network, and efforts to institutionalize elements of it, the Energy Forum attempted to renegotiate the relative authority of diverse knowledge domains contributing to development decision making, emphasizing the knowledge held by participants occupying different positions in the local-global spectrum. Here we see most explicitly how the Energy Forum has sought to empower marginalized social groups by increasing the authority of their knowledge relative to that of institutionally authorized development experts.

Challenging Knowledge Hierarchies

For most intractable development problems, the root cause is not lack of relevant knowledge but institutional structures that systematically exclude relevant groups from contributing their knowledge in effective ways (Chambers, 1983; 1997; Cooke & Kothari, 2001). In Sri Lanka, as in many development contexts, organizational power and expert authority reinforce one another and, intentionally or not, combine to exclude relevant knowledge domains from development decision making. Efforts to include "local knowledge" through more effective direct participation are an important step toward addressing the problem, but without simultaneously focusing on inequalities arising from knowledge hierarchies, these initiatives cannot address the underlying causes of unsustainable development practices. The Energy Forum countered this tendency by challenging the knowledge hierarchies that undermined effective participation by diverse stakeholders. In this way, the Energy Forum worked to create settings where diverse knowledge domains could be put on the table simultaneously and with greater equality, thereby building social and institutional infrastructure to enable sustainable, participatory development decision making (Sclove, 1995; Fischer, 2000). Arguing for the inclusion of local knowledge in development, however, does not go far enough (Cooke & Kothari, 2001). It is necessary to move beyond simple dualities regarding knowledge domains, such as "expert" and non-expert/local. The concept of a knowledge hierarchy suggests a much more complex arrangement of "competing" knowledge domains and types of expertise within a given context. Within Sri Lanka's energy community more and less authoritative knowledge domains constantly interact, including more and less authoritative domains of expert knowledge.

The most important mechanism of exclusion in this context is not outright denial of participation through raw institutional power. Rather, the most important mechanism is systematic delegitimation through highly circumscribed participation. Here, the Sri Lanka case sheds light on the more general lesson of how expertise can inhibit sustainable development. Exclusion operates through the relative authority of different knowledge domains and their prioritization: which receive the most attention, which receive first consideration, and which hold the power to overrule others. Of course, this insight does not deny the ability of powerful institutional players to simply deny or ignore competing perspectives. But such heavy-handed exclusion is relatively easy to identify and analytically straightforward to counter. More often, exclusion operates through more subtle mechanisms, such as minimizing the relevance or diminishing the authority of entire knowledge domains.

The development interventions discussed above show how the Energy Forum's overarching intervention strategy is to challenge knowledge authority structures themselves. This strategy highlights the need to move beyond facile calls for greater inclusion in development decision making by confronting the *mechanisms of exclusion* resulting from knowledge hierarchies. Rather than advocating solely for wider inclusion in development decision-making contexts, the Energy Forum strives to understand how the knowledge hierarchy operates in Sri Lanka's energy community and then to design intervention strategies that directly challenge the operation of that hierarchy. This strategy is founded upon recognition of how expertise embodies not only relevant expert knowledge but also how it is grounded in socially contingent authority structures. In other words, it recognizes how expert knowledge and authority come together as a resource for consolidating power around established institutions and approaches to development planning.

Through its interventions into Sri Lanka's energy community, the Energy Forum challenges knowledge hierarchies by creating 1) localized contexts where participants' expert authority is temporarily equalized (relatively, not absolutely) and 2) institutional structures that solidify authority and project it into the future. In this way, the Energy Forum seeks to mediate and redirect Sri Lanka's overall energy and development planning by flattening the surrounding knowledge hierarchies in ways that systematically empower marginalized knowledge domains. This strategy enables a form of inclusion that is genuinely open to diverse knowledge domains rather than merely allowing token representation of certain perspectives while simultaneously disqualifying that input by setting the terms of discussion so that their underlying knowledge becomes irrelevant. This strategy can easily be generalized to any development context. Because knowledge domains that are lower on relevant knowledge hierarchies are so regularly excluded in development planning, which further exacerbates political and economic inequalities, scholars interested in sustainable development should dedicate special attention to the operation of knowledge-authority structures and to theorizing alternatives.

By intervening to promote more open development processes, the Energy Forum challenged not just the exclusion of one or another particular group, but also the primary mechanism of exclusion—the knowledge hierarchy. By employing this approach, the Energy Forum recognized that even accepted "experts" of various stripes are marginalized relative to experts representing more authoritative knowledge domains. Challenging knowledge hierarchies themselves addressed the *process* of exclusion, not just one or more particular outcomes of that process. Hence, this approach challenges power imbalances head on instead of seeking to reconcile the particular makeup of a specific knowledge hierarchy at a given time. This approach confronts power imbalances head on instead of seeking to reconcile the makeup of a specific knowledge hierarchy at a given time. When the Energy Forum challenged knowledge hierarchies, it disallowed the most powerful groups from determining the terms of discussion, and instead allowed each major stakeholder to contribute its perspective—its knowledge and interests—in its own terms. Creating ways for particular groups to interact around common development questions required the Energy Forum to provide not only alternative contexts for collaboration, but also to fashion alternative structures for interaction. To achieve this goal, the Energy Forum built upon its expertise in community-awareness raising by reflecting that expertise back into the assemblage of development experts—not only toward rural villages. The Energy Forum's authority was based on an innovative mix of competence in diverse development discourses, a steadfast appeal to common development goals, and a widely perceived sense of commitment and good will. The organization leveraged this authority in its efforts to challenge knowledge hierarchies.

Conclusion: Expertise and Sustainable Development

Achieving sustainable development requires going beyond the recognition that many knowledge domains are legitimate within decision making. The task also entails identifying systematically excluded domains, understanding how that exclusion takes place, and devising strategies for effectively including these marginalized perspectives. The existence of knowledge hierarchies creates barriers for effective integration of diverse knowledge domains by linking knowledge authority to institutional power rather than relevance to the problem at hand. When different knowledge domains suggest divergent decision paths, or when the complexity of an intervention requires planners to prioritize inputs, more authoritative knowledge domains typically trump less authoritative ones. Here, we see most clearly the importance of understanding expertise as specialized knowledge *plus* authority. It is authority rather than the possession of relevant knowledge that most sharply distinguishes those considered "experts" from other participants in the development process.

Without an understanding of how expertise is implicated in development failures, genuine and sustained empowerment of intended beneficiaries is impossible, and hence sustainable development is unlikely. The rearrangement of material resources by itself—that is, devising and distributing new technologies or new systems of material interaction while maintaining dominant relations of expertise—leaves existing authority structures intact and thereby precludes sustainable development. It is imperative, therefore, that experts who wish to contribute to more sustainable development initiatives attend to the knowledge hierarchies in which they operate. Unreflective appeals to the authority of expert knowledge—what we typically take to be "expertise"—recreates the very power inequalities that disable devolved decision making and local empowerment. If we consider "development" as empowerment, and "sustainable development" as empowerment that systematically leads to non-exploitative social and human-ecology interactions, then expertise hierarchies must be flattened (not inverted) so that experts representing the experiences, knowledge, and interests of marginalized social groups have a relatively greater voice in development decision making.

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Appendix: Acronyms for the Energy Forum's National Energy Network Schematic

ITDG	Intermediate Technology Development Group, now Practical Action
SEEDS	Sarvodaya Economic Enterprises Development Services
PEU (CEB)	Pre-Electrification Unit (Ceylon Electricity Board)
NSF	National Science Foundation (Sri Lanka)
NERDC	National Engineering Research & Development Centre
MoFE	Ministry of Finance & Economy
ECF	Energy Conservation Fund
MoST	Ministry of Science & Technology
CEA	Central Environmental Authority
ESDP	Energy Services Delivery Project
PFIs	Private Financial Institutions
SIA	Solar Industry Association
Shakthi Viskam Clubs	Student energy clubs

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ARTICLE

What is a clean bus? Object conflicts in the greening of urban transit

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Object conflicts—struggles over the design, definition, and diffusion of technologies—are analyzed to understand the changing history of the greening of bus technologies in the United States from the late 1980s to 2006. Conflicts are examined over the controversy between compressed natural gas (CNG) and emissions-controlled diesel (ECD) buses in four fields: regulations, research on emissions differences, fleet-purchase decisions, and political mobilizations from bus users and environmental justice groups. Given rapidly changing scientific research on emissions and health effects and rapidly changing bus technology, controversies tend not to stabilize or close for long. In general, the trend has been for some of the largest city bus fleets to reverse pro-CNG decisions in favor of ECD. A framework for the analysis of "object conflicts" is developed to elucidate the factors behind the choices between ECD and CNG and to provide a general model for thinking about technology politics and sustainability.

KEYWORDS*:* motor vehicles, urban environments, technology policy, risk factors, emission measurement, decisions, social action, public health

Introduction

Because the greening of urban transit bus fleets is simultaneously technological, scientific, economic, and political, understanding the controversies over definitions of a clean bus requires a multidisciplinary framework. The framework developed here, which is potentially valuable for other sustainability problems where scientific and technical issues intersect with a variety of interested social actors, examines how the different actors interact in a variety of fields of action. In this case, the fields of action include regulations, emissions assessments, purchase decisions, and social movement mobilizations. A broad view of sustainability politics as involving a range of perspectives illuminates why local decision making may vary significantly, and why some regions may end with opposing solutions to a similar problem.

Background

The existing literature on the greening of diesel transit buses and controversies over emissions controlled diesel (ECD) versus compressed natural gas (CNG) is limited to technical reports that evaluate bus emissions and the relative costs of different types of bus technology. There has been a handful of social science studies on sustainable transportation (e.g., Rosen, 2001) and the transition to fuel-cell vehicles (e.g., Hekkert & van de Hoed, 2004; Cohen 2006), but the current study is the first to analyze controversies over clean fuel and bus technology in the United States from a social science perspective. A companion report in this journal issue examines a parallel dispute over ECD and CNG buses in Colombia (Valderrama & Beltran, 2007). In the American case, the legacy of civil rights issues around urban public transit that date back at least to Rosa Parks and the Montgomery bus boycott has added a dimension to the choice of bus technology and contributed to highly polarized debates. The work of Robert Bullard and other researchers at the Environmental Justice Resource Center at Clark Atlanta University provides background on the general politics of "transportation racism" and historical insight into the cases of Atlanta and Los Angeles (Bullard et al., 2004).

The natural gas-versus-diesel controversy can be approached theoretically in many ways; this study develops a framework drawn from science and technology studies (STS). Beginning with Winner's (1986) work on the politics of design, the field has focused on how choices in the design of technological artifacts are simultaneously choices among political values. Ostensibly technical and neutral issues, such as an emissions standard or the design of an emissions technology, can become highly contentious politically. Different groups in society often have dramatically different viewpoints on the optimum technological choice. In some cases, the groups arrive at a middle path that has been studied under the rubric of “boundary objects,” that is, compromise formations that emerge from the negotiations across social worlds (Star & Greisemer, 1989; Clarke & Montini, 1993). Relevant social groups involved in a technological controversy sometimes also are able to achieve closure and settle on a stabilized design (Pinch & Bijker, 1999).

This study contributes to the literature on technology and design by drawing attention to what is termed here “object conflicts,” or definitional struggles over a technology, product, or other form of material culture and the related conflicts over the object’s design and diffusion. In the current case, the analysis centers on the struggle to define what constitutes a “clean bus.” Although in many of the cities discussed here the controversies result in the creation of boundary objects such as “clean fuel” buses, this study draws attention to the instability of such categories and instead directs attention to the ongoing conflicts that emerge around new objects. The lack of stability occurs partly because the technology design, research on health effects, and emissions standards are changing rapidly, but it also occurs because efforts to define a clean bus take place across various fields of action and power, a concept drawn from Pierre Bourdieu’s work (2001). The current study identifies four main fields: regulations, assessments of emissions, fleet- purchase decisions, and public opposition and participation. Rather than define conversion to cleaner buses as a single controversy that can be brought to full closure, the framework developed here takes into account the phenomenon of ongoing technological innovation and scientific research that occurs alongside outcomes in other fields of action. The outcomes in one field reverberate to another to result in ongoing change and controversy.

As a mode of analyzing the politics of technology, a focus on object conflicts provides several benefits over the network models of the 1980s and 1990s (Bijker et al. 1987). The goal of an analysis of fields of object conflicts is not to follow an actor—such as a bus manufacturing firm or an environmental justice group—as it builds a heterogeneous network to achieve success or failure. Although network analyses can provide helpful insights into understanding those processes, the analysis of object conflicts suggests a broader perspective on interlocking fields of conflict. Regulators, emissions researchers, bus manufacturers, fleet managers, and environmental justice groups not only interact, but they work through internal divisions, and they do so in different fields at different times. The outcomes of parallel conflicts and negotiations may create patches of new consensus that reverberate across the other fields, in turn to reopen conflicts or settle ongoing ones. The value-laden conflicts lead to definitions of and choices for the material culture that mediate our relationship to the environment and our own health.

Methodologically, this study is an historical analysis of the diesel-CNG controversy in the United States from approximately 1990 to 2006. The research is based on a comprehensive review of primary sources in the form of electronic and print reports (including government documents), environmental justice group statements, and journalistic reports. Those sources are supplemented by case studies that were developed as part of a broader project on the politics of sustainability and urban design undertaken with Langdon Winner and four graduate students (Hess & Winner, 2005). Of the project’s 30 case studies, four (all conducted by the author) were based on prominent cases of the greening of municipal bus fleets in the United States: Seattle and San Francisco (because of their purchases of hybrid-electric diesel buses); Alameda-Contra Costa County (because of its use of hydrogen-powered buses); and Chattanooga (because of its use of electric buses) (Hess, 2005a-d). During the course of the interviews, the CNG-diesel controversy came up repeatedly, and it was central to the San Francisco case.[1]

The present analysis has several limitations. A comparison of the CNG-versus-diesel controversy in other countries is beyond its scope, as is research on other types of fuels and vehicles. Likewise, many American cities have used either diesel or CNG or both, but this study will focus on the cities with large fleets and, where information is available, the reasons for choosing between CNG and diesel. In addition, the discussion of environmental justice politics will focus only on cities with identifiable mobilizations around the CNG-versus-diesel issue rather than broader environmental justice and air quality issues.

Sustainability Studies and the Clean Bus

Many studies that invoke the term “sustainability” begin and end with the Brundtland report’s emphasis on cross-generational access and preservation in the well-known phrase of meeting “the needs of the present without compromising the ability of future generations to meet their own needs” (WCED, 1987). Although the emphasis has its place, two other perspectives are valuable.

First, an ecological perspective suggests a focus on the level beyond which human consumption of resources and deposits of wastes into an ecosystem (or globally) lead to the failure of the system to regenerate itself or process the wastes (Daly, 1990).

[1] The full case studies are on the author’s web site (http://www.davidjhess.org) and are discussed below where relevant.

From the ecological perspective, the current wave of debate over a "clean bus" could be considered a mirage. No matter how clean the configuration of diesel or natural gas fuels, both are fossil fuels that deplete natural resources and generate greenhouse gases. In this sense, only a hydrogen- or electric-powered bus based on a renewable energy source such as wind would be considered sustainable. When one discusses the issue with fleet managers, they tend to agree: ECD, like CNG, is only a step toward a long-term solution. Other than serving as a bridge technology that makes public transit more attractive, from an ecological perspective neither technology is particularly sustainable. However, recognition of the lack of sustainability can be used to argue in favor of one technology or another. For example, advocates of ECD suggest that hybrid-electric diesel buses are a better bridge technology to hydrogen than CNG because they develop electric power systems. More generally, the "clean bus" controversy as it currently stands suggests that sustainability studies analysts need to consider existing bridge technologies in addition to long-term technological goals.

A second perspective comes from the view that discussions of sustainability can only be ecologically and socially effective if they include equity and justice issues (Agyeman et al. 2003; Hess, 2007). The health effects of urban diesel bus pollution, and especially the pollution of bus idling and bus barns, have become a heated environmental justice issue in some American cities. Because a disproportionate burden of the air pollution from urban bus fleets can fall on low-income urban neighborhoods where people of color reside, the issue of sustainability, at least in some cities, is closely related to that of social justice. The highly polarized politics of urban transit, which have been at the center of American race politics for at least half a century, are prominent in the cases discussed. Race and class politics have converged with health politics to develop an environmental justice basis for opposition to diesel exhaust. Environmental justice concerns have probably been more influential than purely environmental concerns, such as global warming, in creating the political will that has been mobilized to require the greening of United States diesel fleets. Although cleaning up diesel bus emissions would reduce greenhouse gas emissions, the effect of diesel bus emissions on climate change is not the primary issue. The health risks are substantial enough that federal and state government agencies have continued to issue end-of-pipe mandates even in an era of neoliberal governance and under political administrations that have weakened other environmental regulations. As a result, a second contribution to sustainability studies is to develop a better understanding of how environmental justice issues interact with sustainability concerns in situations of technology policy and technological decision making.

Regulating the Clean Bus

Health research has increasingly pointed to the risks of lung cancer, asthma, and other diseases associated with exposure to diesel exhaust. For example, by 1988 and 1990, the National Institute for Occupational Safety and Health and the State of California had each in turn declared diesel exhaust to be a carcinogen, and continued documentation over the subsequent two decades from government units such as the National Toxicology Program and the Environmental Protection Agency (EPA) confirmed the determination (Weinhold, 2002). Similar statements were issued at an international level. The International Agency for Research on Cancer (1989) reviewed the literature and declared that diesel exhaust was a probable carcinogen, and a 1996 report by an international body sponsored by the World Health Organization and several other organizations conducted a similar appraisal on the carcinogenicity of diesel exhaust and recommended actions to reduce exposure (International Programme on Chemical Safety, 1996). In the United States, California became a center for research and policy directed at diesel emissions. For example, emissions were estimated to contribute approximately 70% of the cancer risk from air pollution (South Coast Air Quality Management District, 2000). A report from the California Air Resources Board (1998) noted that diesel exhaust contains 41 toxic air contaminants as defined by the State of California.

Advocacy groups responded to the information by calling for immediate action to clean up diesel fuel, to add particulate traps, and to reduce emissions by other means, such as by switching to natural gas. In 1998, the Natural Resources Defense Council (NRDC) published a report that reviewed the health risks of diesel exhaust and called upon public and private fleets to switch to clean fuels. The health studies that linked diesel exhaust to disease were largely based on diesel-exposed workers and animal experiments, and there was little research on the health effects for bus users or residents along bus lines. However, there was general consensus that diesel exhaust was a carcinogen, and the average outdoor concentration of diesel exhaust in California at that time was estimated to produce about 350 cancers per million people, or 12,000 additional annual cancer cases in California alone (NRDC, 1998). Other advocacy groups, such as the Clean Air Task Force, pointed to several studies of health effects published after 1998 that suggested ongoing risks not only for cancer but also for heart attacks, bronchitis, and asthma (Schneider & Hill, 2005). The study called for action to remediate existing diesel vehicles rather than to wait until replacement vehicles came on line.

The EPA had already taken some steps through the initiation of the Clean Fuel Program that had been authorized by the Clean Air Act of 1990. The program targeted an emissions standard for new fleet purchases beginning with the 1998 model year, identified 22 non-attainment cities in terms of air quality, and mandated that those cities purchase clean-fuel fleets (NRDC, 1998). The goal was for fleet purchases of clean-fueled vehicles to reach 30% in 1998, 50% in 2000, and 70% in 2001. However, the 1998 NRDC report accused the EPA of backpedaling on its own goals in several ways: weakening the emissions standards, delaying implementation, and allowing most non-attainment regions to opt out by demonstrating equivalent reductions through other programs. Although the mandates were weakened, they did pressure urban transit agencies to consider switching to CNG or liquid natural gas (LNG) as a clean fuel. One reason was that fleet purchases are a long-term investment and the predicted future trend was toward regulation in favor of cleaner fuels.

The EPA's emissions standards for an urban bus for the 1998 model year were 4.0 grams per brake horsepower hour (g/bph-hr, or a measure of the pollution produced per unit of energy consumed by the vehicle) for nitrous oxide (NO_x) and 0.05 for particulate matter (PM). Diesel bus manufacturers designed new buses that met those standards, but in 2000 the EPA issued new standards set to begin with the 2007 model year. Those standards were scheduled to drop to 0.2 g/bhp-hr for NO_x, 0.01 for PM, and 0.2 for nonmethane hydrocarbons, with the three-year phase-in beginning in 2007 for NO_x and nonmethane hydrocarbons (Washington State University Energy Program, 2004). In 2000, the EPA also reduced sulfur content mandates in highway diesel fuel by 97% from 500 parts per million (ppm) to 15 ppm, with a stepped phase-in from 2007 to 2010. The diesel industry struggled to meet the new standards, and the low level for NO_x presented an especially critical design challenge (EPA, 2006).

The development of federal standards interacted with two other processes. On an international level, United States standards for diesel vehicles have tended to be higher (that is, mandating lower emissions) than European Union standards. Reasons for the divergence may include geographical differences that affect air quality policy as well as concern with effects of emissions policies on diesel manufacturers. In any case, there has been an ongoing drive to harmonize standards (Peckham, 2003). Arguably, of greater influence has been a second process of standards set at the state governmental level. The most influential state-level regulatory agency in the United States is the California Air Resources Board (CARB), partly because of the size of the state and partly because CARB sometimes enacts more stringent standards than the EPA. For example, in 2000 CARB mandated that transit agencies had to commit either to a diesel or to an alternative fuel path by 2001 (Peckham, 2001; CARB, 2005b). Forty-eight transit agencies across the state opted to pursue the clean diesel path, among them the Alameda-Contra Costa Transit District of the East Bay and Muni of San Francisco, whereas 28 agencies, including Los Angeles and Sacramento, opted for the alternative path (mostly CNG and LNG) (CARB, 2005b). CARB also enacted NO_x standards more stringent than the EPA mandates. Whereas federal standards were scheduled to begin in 2007 with 1.2 g/bph-hr for NO_x and a phase-in to the 0.2 g/bpr-hr standard in 2010, CARB required the level of 0.2 g/bph-hr for NO_x to begin in 2007 (Green Car Congress, 2005a). The three-year difference may seem trivial, but it was important for the diesel industry and bus fleets that rely on diesel.

In 2005, CARB discussed its more stringent standards with bus manufacturers and concluded that the manufacturers would not meet the lower level of emissions until 2010. As a result, the agency proposed three possible amendments: harmonize down to federal standards, do nothing, or require that all diesel-path agencies switch to a clean fuel (which generally meant natural gas) (CARB, 2005b). The Bay Area agencies immediately claimed that the third option would cost hundreds of millions of dollars, and some transit officials protested that the ruling was politically suspicious because Governor Schwarzenegger had recently received a large contribution from a vehicular natural gas company owner (Berthelsen & Marinucci, 2005). CARB eventually opted to harmonize regulations down to the federal standard for the 2007 to 2010 period.

As the proposed CARB amendments suggest, regulatory standards can become hotly contested when the regulations would force a shift away from ECD and place a heavy burden on the diesel industry and urban bus fleets. They have also become contentious from an environmental and health perspective. Environmental groups such as NRDC suggest that the standards have not gone far enough or have undergone retrenchment. The instabilities and changes in regulatory standards have become one significant set of object conflicts in defining what constitutes a "clean" bus and which clean bus technologies will become widely diffused.

Assessing Emissions

The 1998 NRDC study drew on data from CARB to compare the emissions of diesel with CNG buses of the 1996 model year. The data show that emissions of PM, NO_x, and hydrocarbons were 2-3 times higher for diesel than CNG, and the carbon dioxide (CO_2) emissions were about 12% higher for diesel. NRDC also presented a comparison between a hybrid-electric diesel bus of that time and a CNG bus, again showing that the PM and NO_x emissions favored the CNG bus. The study considered battery and hydrogen technology as other clean fuel alternatives but dismissed them as not practical. In other words, at that time natural gas and diesel were the two available alternatives. The report's success stories focused on CNG and LNG as providing significant emissions improvement on the performance of diesel buses. NRDC's position in favor of CNG was politically important because it potentially influenced regulatory agencies which it criticized as overly lax, and the organization's report was used as a resource in some of the local environmental justice mobilizations against "dirty diesel" (NRDC, 1998).

The technology was changing very rapidly, and test data for new ECD buses, which ran on ultralow sulfur fuel and used particulate traps, soon became available. For example, a 2002 CARB study compared existing CNG buses with the new ECD buses equipped with particulate traps. The preliminary study only compared ECD with the old CNG buses, and a report by NRDC cried foul. Another confounding factor was that particulate traps need to be changed after 150,000 miles, and consequently any real-world applications would require a monitoring system (NRDC, 2002). CARB's follow-up study provided a more head-to-head comparison between an ECD bus and a CNG bus that had a new oxidation catalyst, a device that played an equivalent role for CNG that the particulate traps did for diesel. The ECD bus had about double the NO_x emissions, but the PM emissions were equivalent. Although the PM emissions for the ECD bus were more toxic, the CNG bus emitted more aldehydes and more ultrafine particles, which may have higher health risks than larger particles (CARB, 2002a; 2002b; 2004; 2005a). Based on the comparisons that showed risks associated with both technologies, transit agencies could conclude that from an emissions viewpoint ECD and CNG were roughly equivalent.

Subsequent studies attempted to translate emissions differences into health effects. Using a cost and "quality adjusted life years" ratio model, one analysis suggested that CNG and ECD bus technologies produced similar reductions in expected health damages in comparison with older diesel buses, but CNG had a "slight edge" due to the lower rate of NO_x emissions. However, the ECD buses accomplished the reductions in expected health damages at much lower cost than CNG, and consequently one could defend a choice of ECD because it would allow a more rapid retirement of older, dirty diesel buses (Cohen, 2005). Another study of a CNG bus with no after-treatment versus ECD buses showed that the CNG bus emitted more benzene and formaldehyde and that its emissions had higher mutagenic activities (Kado et al. 2005). In brief, the health-effects studies did not clearly favor ECD or CNG. They suggested substantial interpretive flexibility in assessing comparative health effects, with much depending on technical issues such as the type of emissions technology being compared and the assumptions made about the relative value of health savings versus the relative cost of the different technologies. The new ECD technology had closed the gap substantially on the comparative health risks of diesel and natural gas.

By the early 2000s, hybrid-electric diesel bus technology was becoming widely available, and additional CNG-diesel comparisons were undertaken. The Northeast Advanced Vehicle Consortium (2000) performed for the United States Navy a series of tests showing that when the hybrid-electric diesel buses were operated on ultralow sulfur fuel, their levels of PM, NO_x, and nonmethane hydrocarbons were comparable to those of the CNG buses with oxidation catalysts. The hybrid-electric diesel buses also had double the fuel economy of CNG buses (based on an algorithm that converted natural gas to an equivalent in gallons of diesel fuel), emitted 10–40% lower levels of greenhouse gases, and released much lower levels of carbon monoxide. In other words, the new diesel technology had become clearly favorable to CNG on several significant metrics. Although hybrid-electric CNG buses were not tested, the hybrid-electric diesel tests included a condition in which the regenerative braking was turned off. The additional condition allowed a more accurate comparison between the diesel and natural gas buses.

In 2006, the National Renewable Energy Laboratory (NREL) announced the results of tests for the Washington Metropolitan Area Transportation Authority of CNG buses with lean burn engines and oxidation catalysts versus diesel buses with particulate traps and ultralow sulfur fuel. The definition of "clean diesel" did not include hybrid-electric diesel, but a variety of both CNG and diesel buses was tested, including some diesel buses that had exhaust-gas recirculation. The results varied substantially by bus but generally favored CNG on the metric of NO_x and PM, and the study concluded that aldehydes from both types of buses approached ambient background levels (Melendez et al. 2005).

Giving the rapidly changing technological innovations and the instability of emissions data, two types of intersecting issues emerged. Diesel technology was innovating more rapidly and in some ways had leapfrogged over CNG, but if similar technologies were employed on CNG, then CNG might be cleaner. As a result, at any point in time the two alternatives were roughly equivalent. Diesel did not fare as well as CNG on the metric of NO_x emissions, but future health research might show that the ultrafine particles especially associated with CNG constituted a more serious health risk. The ambiguity of the scientific research on emissions levels was important, because different parties could draw different conclusions. In other words, fleet managers who saw cost and convenience advantages in diesel could opt to return to diesel, whereas environmental justice groups could conclude that where head-to-head tests were done with equivalent levels of technological innovation, CNG was a safer and cleaner fuel. The absence of closure in emissions testing and bus-technology design helped create continuing shifts in purchase preferences and differential outcomes of grassroots mobilizations.

Making a Purchase Decision

The technical data on emissions intersected with emerging economic data from the transit agencies on the relative costs of purchase price, infrastructure investments, maintenance, and fuel for natural gas versus diesel buses. Because the decisions were especially complicated and have changed over time, this section will be somewhat more detailed than the two previous sections. It will focus on cities with data, either from interviews or publicly available sources, about reasons for the choice in favor of CNG or ECD (see Table 1).

One of the complicating factors that affected the choice between ECD and CNG was the emergence of hybrid-electric diesel buses. A study by the New York Metropolitan Transportation Authority in 2003 noted that, for the 2003-2004 purchase, hybrid-electric diesel buses had come down in price from US$465,000 to US$385,000 each, in comparison with US$290,000 per bus for conventional ECD and US$320,000 per bus for CNG (Chandler et al. 2002). Satisfied with the hybrid-electric diesel buses, the agency ordered 500 more vehicles in 2005 (Green Car Congress, 2005b). A subsequent study released in 2006 by NREL compared CNG and hybrid-electric diesel buses in New York City and found that hybrid-electric diesel buses had fewer repairs and higher fuel economy than the CNG buses (Chandler et al. 2006).

Although hybrid-electric buses cost more than conventional ECD, a test by Seattle-based Metro Transit, which as of 2005 had one of the largest hybrid-electric diesel fleets in the country, found that those vehicles rapidly made up costs in comparison with ECD. Based on extensive testing and experience, the fleet manager estimated that the new hybrid-electric diesel buses would last 14-16 years and would pay for themselves within eight years due to lower repair costs and more efficient fuel consumption than conventional ECD (Hess, 2005c).

The up-front purchase price differential between CNG and ECD buses was also declining, and for fleet managers who were already on a CNG track, the closing of the initial purchase price gap made CNG increasingly attractive. In the late 1990s, a CNG bus cost US$65,000 to US$75,000 more than its diesel equivalent, but by the time of the New York study the differential had declined to only about US$30,000 (Eudy, 2002). However, for fleet managers who were contemplating a switch from diesel, or who had not fully invested in CNG, other factors made the comparison less attractive for CNG. For example, conversion to CNG required a substantial investment in refueling stations and staff training. Regarding infrastructure investment, in Los Angeles a contract for three refueling stations in 1999 cost US$35 million (Energy Futures, 2000), and regarding operating costs, a study by the Greater Cleveland Transit Authority, which had used both diesel and CNG buses, found that the fuel cost for ECD and CNG in 2003 was equivalent, but the labor and parts costs were significantly higher for CNG. Taking into account the difference in purchase price, fuel, labor, and parts, the Cleveland agency concluded that a CNG bus was about 20% more expensive to operate per mile than an ECD bus (Heywood et al. 2002). Likewise, a comprehensive survey of transit agencies using CNG, conducted by NREL and published in 2002, found that most fleets reported higher costs for CNG than diesel (Eudy, 2002). However, a few fleets experienced lower CNG fuel and maintenance costs. The

Table 1 The CNG/ECD Controversy in Eight Large Cities in the United States

City	Returned to Diesel	Stayed with Diesel	Stayed with CNG
Atlanta			x
Boston	x		
Cleveland	x		
Los Angeles			x
New York	x		
Oakland		x	
Seattle		x	
Washington, DC	x		

study suggested that transit agencies with large CNG fleets and a high degree of training were more likely to experience the lower CNG costs. However, even the Los Angeles Metropolitan Transportation Authority, with its large CNG fleet, noted that although fuel costs were equivalent for CNG and diesel, annual maintenance costs were 15-20% higher for CNG (Energy Futures, 2000). Another study, written for the natural gas industry, admitted that another drawback for CNG was a lower range and payload than diesel but argued that reliability and fuel economy problems had been overcome by the late 1990s (Watt, 2000). Again, the claims about overall cost differentials allowed some interpretive flexibility.

Statistics from the American Public Transportation Association (2003) indicate that in the early 2000s the aggregate number of CNG buses continued to grow, while that of diesel buses shrank. However, if one looks more closely at the trends in some of the large fleets, during the early 2000s several of the cities with large, mixed fleets were attempting to shift back to diesel, whereas some of the large transit agencies that had committed to CNG were close to completing their conversions. Consequently, the growth in CNG may have reached a plateau by 2004, and barring a regulatory intervention or a dramatic shift in the relative difference of fuel costs, diesel was winning in some of the largest cities.

One factor in favor of the shift back to diesel was the deregulation of the natural gas industry. During the mid 1990s, the industry had convinced some agencies to shift to CNG, but its role as an advocate of CNG had weakened by the early 2000s. According to one fleet manager, during the early- and mid-1990s sales were relatively flat for the natural gas industry, and bus fleets were seen as a potential area for growth (Hess, 2005c). Offers from natural gas companies to build some of the refueling facilities converged with other factors to make CNG attractive at that time: the impending implementation of the EPA standards in 1998, the emerging data on the lower emissions of CNG than the mid-1990s diesel buses, and the transit agencies' genuine preference for cleaner buses.

Some transit agencies resisted the natural gas industry entreaties and offers. For example, Alameda-Contra Costa County Transit District (AC Transit) was "pushed very heavily" to shift to natural gas (Hess, 2005a). The agency tested CNG buses, but decided not to adopt them because of cost and reliability concerns. Later, the higher levels of ultrafine particles, as well as of formaldehyde, became a factor in support of ongoing decisions in favor of diesel. The natural gas industry also pressured Metro Transit of the King County area surrounding Seattle during the mid-1990s. In response to what the fleet manager described as a "full-court press," the transit agency expressed numerous concerns to the county council: the high increase in refueling time in a system that did not leave any slack, the small size of existing gas lines (which could not fuel the fleet during the 11 pm to 4 am shift), concern that the heavy draw on the gas system might extinguish pilot lights on furnaces for residential and business customers, apprehension about possible explosions from natural gas in existing or converted diesel bus barns, and an estimated total cost of US$100 million to buy the more expensive CNG buses and retrofit existing bus barns (Hess, 2005c). The county council ignored the transit agency's advice and decided to mandate the fleet's conversion to liquid natural gas (which the agency saw as somewhat more acceptable), but shortly afterward an election resulted in a change of the party composition of the city council, and the new Democratic majority reversed the decision (Hess, 2005c).

However, not all transit agencies rejected the CNG option. In southern California, where air quality issues were particularly strong and regulatory mandates were different, several transit agencies pursued the CNG path. Likewise, the Metropolitan Atlanta Rapid Transit Authority (MARTA) opted to begin purchasing CNG buses in 1994, when the Atlanta Gas Light Corporation offered to pay for the entire cost of a $2.5 million refueling facility, maintain the facility, and help the agency purchase CNG buses (Transit Cooperative Research Program, 1998). In addition, the federal government provided some support for CNG as part of an effort to showcase clean transportation during the 1996 Olympics (Ashburn, 2004). By 2001, half the agency's bus fleet was CNG, and by 2004 the proportion of CNG buses had grown to 74% (Ashburn, 2004). In 2000, the Washington Metropolitan Area Transportation Authority (or Metro Transit of Washington, DC) entered the CNG market with a purchase of about 100 CNG buses, and it continued to purchase CNG buses through 2004, when the projected number was at about 400 (compared to approximately 1,200 diesel buses) (Washington Metropolitan Area Transportation Authority, 2006a; 2006b). By 2002, several large and mid-sized transit agencies had CNG fleets, including El Paso, Long Island, Los Angeles, Orange County, Perce County, Phoenix, Sacramento, San Diego, Syracuse, Tempe, and Tucson (Natural Gas Vehicle Coalition, 2003).

Various internet searches and interviews did not uncover evidence of subsidies or pressure from the diesel industry similar to those of the natural gas industry. From the 1990s to the present probably the primary incentive in favor of diesel was the lower up-front cost per bus, the lower maintenance cost (at least for inexperienced agencies undergoing a transition), and the comfort level that most transit agencies had with the familiar technology. During the late 1990s and early 2000s, two major changes started to shift the preferences of agencies that leaned toward CNG or were considering switching to it. First, agencies found that they could reduce diesel emissions significantly by retrofitting buses with particulate traps and switching to ultralow sulfur fuel; as a result diesel and CNG emissions became more equivalent (as the 2002 CARB study indicated). Second, the natural gas industry was deregulated, and as a result support programs for natural gas declined. For example, in 1999 Atlanta Gas Light Corporation shifted from marketing and service to wholesale, and its resources shifted into competition for customers rather than support for natural gas fleets (Ashburn, 2004). Furthermore, natural gas prices increased after deregulation, and fueling stations for natural gas declined in the city. By 2004, the Atlanta Gas Light Corporation had cut its natural gas fleet from 600 to 9 vehicles, and other companies in the city (such as Checker Cab and Bell South) had also cut their fleets down to a minimal level. However, Atlanta's regional transit agency already had two natural gas refueling facilities, so it was less dependent on the disappearing public fueling stations than were the private corporate fleets (MARTA, 2004). The existing reports give no reasons why MARTA remained on the CNG path; sunk costs were probably a factor as well as the environmental justice issues being raised regarding neighborhood air pollution levels across race and class lines.

As a result of the changes in both diesel technology and the natural gas industry, several large transit agencies that had invested in CNG began to shift back to diesel. For example, in 2005, the Greater Cleveland Regional Transit Agency had 160 CNG buses (in a fleet of 650), but it decided to shift to clean diesel (Exner, 2005). The agency argued that CNG buses had more mechanical problems and were more expensive. Likewise, New York's transportation agency stated in 2005 that it wanted to stop buying CNG and shift to hybrid-electric diesel buses (DieselNet.com, 2005).

Another example of the shift back to diesel occurred in Washington, DC. The momentum for CNG appeared to be going strongly until May, 2004, when the new chairman of the board, Robert Smith, began pushing the agency to shift away from CNG (Layton, 2004). The board debated a proposal to purchase 200 more CNG buses versus using the same funds to buy 196 diesel and 50 hybrid-electric buses that would run on either diesel or natural gas. Smith (2004) argued that the effects on aggregate emissions of a switch from CNG were minimal, but the lower cost of new diesel buses would allow the agency to purchase more buses and therefore decommission the older diesel buses more quickly. Furthermore, he argued that the CNG buses presented a security risk because a terrorist could commandeer a CNG bus and drive it into a building (Layton, 2004). The proposal prompted a critical editorial from representatives of NRDC and the Sierra Club who supported CNG buses over new diesel. They argued that new diesel would not meet the 2007 federal standard and suggested that hybrid-electric diesel buses were not a viable option because the buses were still experimental (Negin & Wenzler, 2004). In an editorial reply, Smith argued again that the agency could buy more clean buses and noted that other transit agencies were shifting to hybrid-electric diesels (Smith, 2004). In 2005, the agency approved a purchase of ECD and hybrid-electric diesels (Ginsburg, 2005).

Another shift back to diesel occurred in Boston in 2002, when the Massachusetts Bay Transportation Authority (MBTA) obtained from the state's Department of the Environment a modification of a consent decree. The change allowed the regional transit agency to purchase any clean-fuel technology but in return required the purchase of 200 new buses to replace its oldest vehicles. That same year the agency received an expert-panel report that recommended new purchases of ECD buses over CNG (Heywood et al. 2002). The reasons given were the minimal difference in emissions between the two bus types, lower operating costs and initial expense for ECD buses, need to economize on initial purchases to retire more of the older buses, and delays in the construction of natural gas infrastructure facilities. The agency shifted back to diesel in 2004, when it purchased 600 low-emission diesel buses and said that it would retrofit the remaining buses (Gandelman, 2004). At that point, 120 CNG buses were in operation, but in a draft report for 2004 the agency mentioned only 44 CNG buses in the total bus fleet of about 1,000 (MBTA, 2004).

In summary, the shifts in the purchasing preferences of some of the largest transit fleets suggest that diesel had recovered after the setbacks of the mid 1990s. However, the idea of "clean diesel" did not always play well with bus rider groups and environmental justice organizations, and, as a result, not all agencies were equally in a position to select "clean diesel."

Mobilizing Political Change

In some cities, grassroots mobilizations by environmental justice groups affected the shift to CNG or diesel buses. Mobilizations were prominent in five cities: Atlanta, Boston, Los Angeles, New York, and San Francisco. In all cases, environmental justice groups entered the political arena to restrict the decision-making leeway of transit agencies and to shift spending preferences in favor of cleaner vehicles. In New York and Boston the groups achieved changes from their respective state governments, in San Francisco the groups worked through the city government and city-level voter proposition system, and in Atlanta and Los Angeles the groups operated through the courts.

In New York, an environmental justice mobilization focused on the fact that six of the eight bus depots in the city were located above 96th Street, that is, in or near low-income communities of ethnic minority groups (WE ACT, 2004a). In 1995, several members of the New York State Assembly, together with Manhattan Borough President Ruth Messinger, called on the New York Metropolitan Transportation Authority (MTA) to shift to CNG buses (Tri-State Transportation Campaign, 1996). WE ACT, an environmental justice group based in West Harlem, began a campaign against the diesel bus depots and advocated conversion to CNG (WE ACT, 2004b). Governor Pataki and state legislative leaders responded three years later by issuing the Clean Fuel Bus Plan, which included the following goals: retrofitting three depots for CNG, making all new depots CNG-compatible, retrofitting existing vehicles, and purchasing 250 hybrid-electric diesel and 300 CNG buses in a fleet of about 4,500 buses (Governor's Office of New York, 2000). Six months later, WE ACT filed an administrative complaint with the federal Department of Transportation alleging that MTA located diesel bus depots and parking lots in a discriminatory pattern (WE ACT, 2000). WE ACT also developed a map with alternative locations for the bus depots.

In 2003, the transit agency responded in a way that was unsatisfactory to the coalition: it closed a bus depot downtown and reopened one in East Harlem that had been remodeled to include a roof. The agency did shift to ultralow sulfur diesel fuel, and it purchased 300 CNG buses (Tuhus-Dubrow, 2003). The federal Department of Transportation finally reached a decision that, according to WE ACT, "acknowledged the community's cause for concern while declining to find actual civil rights violation" (Prakash & Corbin-Mark, 2006). In 2004, WE ACT and community residents began negotiations with MTA regarding the bus depots, and a year later the two sides developed a letter of agreement to meet regularly and to prioritize the cleanest buses for the depots in northern Manhattan. The agency also agreed to rebuild the oldest depot to minimize its impact on the neighborhood. However, as noted above, the agency was shifting away from CNG toward hybrid-electric diesel (Chan, 2005).

The Boston case is like that of New York on two major grounds: the goal of cleaner buses was achieved through action at the state-governmental level, and eventually the transit agency opted for clean diesel over CNG. In Massachusetts in 1996, Governor Weld pledged that MBTA would buy no more diesel buses, and the Boston area transit agency responded by testing two CNG and two hybrid-electric diesel buses (Duffy, 2000). After testing the buses, MBTA decided that because the hybrid-electric diesel buses at that time did not have enough power for the hills, CNG was the better option (Duffy, 2000). Again, the environmental justice mobilization occurred alongside the general policy shift. In 1997, the environmental justice organization Alternatives for Community and Environment led a coalition in the Clean Buses for Boston campaign, and three years later they formed the T Riders Union (Egleston Square Neighborhood Association, 2002; Heart of the City, 2005). The coalition pushed for CNG as a cleaner alternative to diesel, and in 2001 it obtained an administrative consent order from the Massachusetts Department of the Environment that required MBTA to purchase 350 clean-fuel buses and to retrofit existing buses (Daniel, 2002; Alternatives for Community and Environment, 2006). The agency responded by purchasing 350 new CNG buses, shifting to ultralow sulfur fuel, and retrofitting old diesel buses (MBTA, 2002). However, as noted above, in 2002 the agency obtained a modification of the consent order, which had allowed it to shift back to diesel in its 2004 purchase. Environmental justice advocates saw the decision as a setback, and they responded by obtaining an agreement with the agency on an extensive monitoring system to ensure attainment of the claimed emissions reductions (Saleos, 2003).

San Francisco faced similar pressure from environmental justice groups to shift to CNG, but the city's transit agency, Muni, never made substantial CNG investments, and much of the battle was fought out through local political mechanisms rather than the state government. Environmental and health groups had the support of sympathetic members of the city's Board of Supervisors, and beginning in 1997 the board began passing resolutions against continued diesel bus purchases (Kay, 2004). Muni's fleet included some pre-1991 diesel buses that were particularly controversial because of their high emissions and the concern that they were adversely affecting air quality in low-income neighborhoods such as Hunter's Point. A major controversy erupted in 2001, when Muni announced that it was going to purchase new buses (Hess, 2005d). The Board of Supervisors supported a coalition of health, environmental, and neighborhood groups that wanted the agency to purchase CNG buses, but Muni argued that the buses were less reliable and lacked power for the city's hills. In an interview with me, a Muni spokesperson claimed that the coalition "lacked the expertise and the dedicated resources to really understand the transit agency's operating realities, funding requirements, and technology" (Hess, 2005d). The coalition disputed the characterization and pointed to its experts from Pacific Gas and Electric, NRDC, the American Lung Association, and the city's environment and public health departments.

The city Board of Supervisors was sympathetic to the coalition and worked out a compromise with Muni that enabled the transit agency to purchase 100 new diesel buses instead of the proposed 200-300 buses and at the same time to test a CNG bus. After a delay, the agency tested two CNG buses and decided that they were less reliable than diesel buses (Kay, 2002). In 2002, the agency asked for 18–24 months to complete studies, and, in response to the delay, the coalition developed the "Dump Diesel" campaign to urge more immediate action (Our Children's Earth, 2002). The coalition disputed the methodology of the tests and in 2004 introduced Proposition I, which required the agency to replace its pre-1991 buses. Because the proposition left open the question of bus design, ECD was potentially acceptable if it could meet state emissions standards. The proposition passed, but it was soon overtaken by a ruling from CARB, which mandated the phase-out of all old diesel buses and recognized hybrid-electric diesel buses as meeting the new standards. In 2004, Muni began purchasing hybrid-electric diesel buses and also announced a plan to have an all-electric fleet by 2020. Although the coalition continues to watch Muni, it found the new hybrid-electric diesel buses acceptable because of their low emissions.

In Atlanta and Los Angeles, the fleet-purchase decisions continued on a CNG path, with environmental justice concerns a contributing factor. Although in Atlanta a more influential factor was probably the huge sunk costs in infrastructural investment, environmental justice groups also pushed for conversion of the fleet to CNG. For example, in 2000, the Metropolitan Atlanta Transit Equity Coalition (MATEC) filed a complaint against MARTA alleging discriminatory practices (Environmental Justice Resource Center, 2000). One of the areas of complaint was the unequal distribution of CNG and diesel buses. The Hamilton garage served buses that ran in neighborhoods for mostly ethnic minority groups, and at the time the facility also serviced the oldest dirty diesel buses (Bullard et al. 2004). In contrast, the two garages that served high proportions of non-minority riders (Perry and Laredo) were already converted to CNG or in the process of conversion. After the complaint was delayed at the federal level for 15 months, MARTA and MATEC entered into mediation. The results were not satisfactory to the environmental justice coalition, but MARTA responded by building new bus shelters and buying new ECD buses (Bluestein, 2004; Bullard et al. 2004). By 2004, various regional plans listed conversion of the Hamilton garage to CNG as a priority (Atlanta Regional Commission, 2004; Ford, 2004), and by 2006 the entire fleet was either CNG or ECD (MARTA, 2006a). However, in 2005 MARTA purchased 40 ECD buses, and at a 2006 meeting the board also discussed the relative costs and benefits of CNG versus ECD, so the long-term decision over clean bus options was still unresolved (MARTA, 2005; 2006b).

In Los Angeles, the effect of grassroots mobilizations on fleet-purchase decisions was arguably the greatest, but the mobilizations occurred within a series of decisions already underway in favor of greener public transit. For example, the city had purchased a large number of buses during the 1980s for the 1984 Olympics, and the older buses needed replacement. The agency had begun testing alternative fuel buses in 1989, when it purchased 30 methanol buses and 10 CNG buses (LACMTA, 2006b). After testing the new buses, in 1993 the Los Angeles County Metropolitan Transportation Authority (LACMTA) committed to a long-term policy to purchase only alternative fuel buses (LACMTA, 2006b). Based on further use, the agency determined that methane-powered buses suffered from maintenance and reliability problems, so in 1995 the agency repowered those buses with diesel and shifted to additional CNG buses (LACMTA, 2004, 2006b).

In 1992, the Labor/Community Strategy Center formed the Bus Riders Union to advocate for a number of reforms that included the greening of bus emissions (Bus Riders Union, 2005b). LACMTA announced a fare increase two years later, and the Bus Riders Union sued the transit agency in federal court for civil rights violations (Berkowitz, 2005). The central legal claim, that the agency had developed a separate and unequal transit system, was based on the high subsidies and investments going into rail transit. The Bus Riders Union argued that the rail subsidy largely benefited middle-class and white customers, whereas bus transit suffered from inattention, disrepair, frequency problems, and poor safety records. To avoid a trial, in 1996 Mayor Riordan signed a ten-year consent decree that, in effect, put bus purchase decisions in the hands of a court-appointed "special master," who supervised implementation (Berkowitz, 2005). The decree included a load-factor requirement that limited the number of standing passengers during a 20-minute period. When the load limit was exceeded, the special master had the right to mandate that LACMTA add buses (Rabin, 1999). After a few years of negotiations, in 1999 the special master ordered LACMTA to relieve overcrowding by buying 532 additional CNG buses (in a fleet of about 2,200), that is, a figure over and above the 2,095 that LACMTA had promised to purchase before 2004 (Rabin, 1999.). LACMTA chief called the decision "excessive" and said that it would cost over US$400 million during the following five-year period (Rabin, 1999). LACMTA ended up appealing the decree all the way to the United States Supreme Court, and it lost (Bus Riders Union, 2002).

In 2000, LACMTA staff recommended a purchase of 370 ECD buses. The Bus Riders Union, in coalition with NRDC and other groups, played a significant role in creating the groundswell of opposition that led the board of the transit agency to continue with the CNG-only policy (Bus Riders Union, 2000; Rabin, 2000). The Bus Riders Union framed diesel as "death on wheels," called for "zero tolerance for carcinogens," and threatened lawsuits (Bus Riders Union, 2000). With the purchase in 2000, the fleet was targeted to become about 86% CNG (Rabin, 2000). By 2005, the agency had 2,045 CNG buses in a total of about 2,700 buses and was in the process of converting completely to CNG buses (LACMTA, 2006a; 2006b). In that year the special master ordered LAMTA to purchase an additional 134 buses (Bus Riders Union, 2005a).

In summary, in Boston and San Francisco environmental justice groups adopted a relatively flexible attitude regarding what constitutes a clean bus. Although they favored CNG, some statements indicate sympathy with the argument that ECD and CNG have over time achieved comparable emissions, and that the cost savings of opting for ECD over CNG allows a more rapid retirement of older and more polluting buses. In contrast, in Los Angeles the Bus Riders Union emphatically equated diesel with racism and pushed for CNG. Although environmental justice organizations were less influential in other cities, in Los Angeles the consent decree and the decisions of the special master were a determining factor in fleet-purchase decisions during this period.

Conclusion

What constitutes a clean bus? The question suggests an analysis of the politics of definitions or "object conflicts" that articulate political and economic trade-offs with changing technology design and emerging scientific knowledge about health risks and emissions levels. As of 2006 there was rough parity in emissions between a CNG bus with an oxidation catalyst and a hybrid-electric diesel bus with ultralow sulfur fuel and a particulate trap. Because neither was a zero-emissions vehicle, decision makers and grassroots groups were left in a position of choosing their poison. New health research on the effects of ultrafine particles, aldehydes, and carbon monoxide indicated that the balance in favor of one type of "clean fuel" over another could shift, just as new technologies could allow one type of bus to leapfrog over the other. In the background hydrogen fuel-cell buses continued to be tested, but they remained prohibitively expensive. Biodiesel use was growing, but generally at mixes of 5–10% of the diesel fuel. A few cities had purchased electric-battery buses, but generally for short runs on flat surfaces, such as Chattanooga's downtown circulator. Furthermore, to the extent that the fuel cell was powered by natural gas reformulation, or the electric battery was powered by a fossil-fuel burning electrical power plant, pollution was displaced to another point in the region or country.

Object conflicts that define a rapidly changing understanding of the "clean bus" take place in multiple arenas. In this case, the CNG-diesel controversy in the United States was traced in four fields of conflict and negotiation: regulations based largely on health risks, emissions- assessment studies, fleet-purchase decisions, and public mobilizations in the form of environmental justice groups that have influenced political leaders, state and local governments, the courts, and polls. The outcome of a controversy in one field can affect conflicts in another; sometimes a long, hard-fought battle at one level, such as San Francisco's Proposition I, can be trumped (or, in this case, supported and made obsolete) by a decision from the state government's regulatory agency. Likewise, emerging emissions data or health studies can rapidly shift the relative desirability of one technology over another, and changes in bus- emissions technologies also can shift economic and environmental assessments.

One hope of this author is that the concept of object conflicts and the methodology of analysis across fields of action may be of general value to sustainability researchers and policymakers. Much of what emerges as policy is a compromise formation that involves constant adjustments, as scientific research produces new insights and concerns, technological innovations respond to health and regulatory issues, cost considerations shift in response to global economic changes and technological innovations, and grassroots organizations interpret the changes and modify (or harden) goals. The question of "what is a clean bus" is one example of a politics of definitions that is constantly evolving and changing. From this perspective "sustainability" is not a goal that can be easily defined in a neutral and unbiased way, but a field of contestation that involves ongoing negotiations over fundamental definitions.

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ARTICLE

Diesel versus compressed natural gas in *Transmilenio*-Bogotá: innovation, precaution, and distribution of risk

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During the period 1998–2000, municipal officials in Bogotá implemented a new transportation system for the city. *Transmilenio* became the first major mass transportation system in the world to use only buses. The authors examine here the process that led to the design decision to power all of the buses with diesel fuel. The main finding is that the various public and private partners sought to accommodate themselves to the alternative that was deemed to be less risky. The diesel option was the outcome of contingent negotiation and distribution of responsibilities among the different interests. The dynamics of these processes were heavily influenced by a precautionary posture.

KEYWORDS: motor vehicles, urban environments, technology policy, risk factors, public health, cost-benefit analysis

Introduction

On December 1, 2000, 450 new articulated buses began to provide transportation services along the main urban transit corridors in the city of Bogotá, Colombia. The fleet replaced approximately 1,140 older buses and served about 850,000 passengers per day. From a technological perspective the new fleet represented a radical change for the city, but in one significant way the new vehicles were entirely consistent with the previous public transportation system. The replacement buses were powered by diesel fuel.

The design and implementation of the new system involved numerous organizational and technological decisions of which one of the most controversial was the use of diesel fuel rather than compressed natural gas (CNG). From a broad sustainability perspective, both diesel and CNG are fossil fuels that generate greenhouse gases, and both appear to be at or near peak production on a global level. However, several factors might have favored the selection of CNG. Colombia has extensive natural gas reserves and government officials had been encouraging transportation authorities to convert their fleets to natural gas. Moreover, Bogotá had earned an international reputation for sound urban planning and a demonstrated responsiveness for creatively fusing sustainability and innovation (Jones, 2002; Institute for Transportation and Development Policy, 2006). Furthermore, when the decision was being made during the late 1990s, CNG was deemed a much cleaner fuel that promised significant environmental and health benefits for the Bogotá region. In contrast, continued use of diesel as the main fuel for the public transportation system presented long-term uncertainty regarding increased cancer, asthma, and other diseases (International Agency for Research on Cancer, 1989; International Programme on Chemical Safety, 1996; *El Tiempo*, 2006). Indeed, as city council member Alfonso Prada noted, “In the city council, the debate was around what was the cleanest fuel. That is what really matters; it was the essence. Which one pollutes less? There is no debate about costs.”

Prada’s comment suggests that the precautionary principle, rather than a narrow cost-benefit calculus of the trade-off between the health risks of continued diesel emissions versus the operational costs of CNG conversion, guided at least some council members as they deliberated over the complex issues of vehicle emissions, air quality, and fuel preferences. Had the precautionary principle been translated into system-design choices, Bogotá’s model-bus system might have in the end been fueled by CNG. However, something happened on the way from principle to practice. The following analysis provides a post-mortem analysis of Bogotá’s CNG-diesel controversy. This history is interesting in one sense as a basis for comparative, cross-national insights on the CNG-diesel controversy (see also Hess, 2007). However, the case study is also used here to open a broader discussion about some of the problems that can emerge in public-private partnerships where public risks related to health and environmental quality collide with private risks of businesses concerned about profitability and possible technological failure. Although we note, like Ferguson (1997), that privatization has some limits, we attempt to delineate strategies for successful public-private partnerships where two different notions of risk need to be negotiated and the technological choices are not straightforward.

Theoretical Background

Scholars agree that transportation is a key sector in the discussion on sustainability (Hall, 1993; Rosen, 2001; Crane & Schweitzer, 2003; Amekuzdi & Meyer, 2006). Continuing use of the internal combustion engine to power airplanes, trains, trucks, ships, buses, and cars around the world is having pronounced impacts on global climate change even though the extent of these effects remain difficult to measure. Urban transportation, in particular, is a key area for inquiry because it has direct implications for proximate populations (Hall, 1993). If we consider definitions of sustainability such as "the use of renewable resources at below their rates of regeneration" and "the use of non-renewable resources below the rate of development of renewable substitutes," we have a basis for considering air pollution under the first definition and depletion of fossil fuels under the second one (Amekuzdi & Meyer, 2006).

However, sustainability refers to a macro level; some would say to an ecological level. Therefore, a growing literature points to the relationship between sustainability and "environmental justice" or "social exclusion." Developed in the United States, environmental justice is not only a theoretical concept, but also serves as a policy mandate. Under Executive Order 12898 from 1994, all federal decisions are to benefit all social groups equally and, if negative impacts are unavoidable, no social group, especially ethnic and poor minorities, should suffer more than others. This mandate has been included in transportation-planning processes undertaken by federal agencies in the United States (Pfeffer et al. 2002; Agyeman & Evans, 2003; Chakraborty, 2006). In the United Kingdom, a similar debate has centered on groups traditionally excluded from formal planning processes. The aim, as proposed recently by Lucas (2006), should not be to plan for mobility, but to promote accessibility. That is, planners should seek to ensure better access to employment, shopping, and family and leisure activities, and not only in terms of enhancing physical mobility.

Environmental justice proponents also contend that it is important to assess the impact of planned or constructed projects on actual populations (Mills & Neuhauser, 2000; Pfeffer et al. 2002) and to better incorporate sustainability and environmental justice considerations into early planning. This approach implies the revision of current practices among agencies and the formulation of strategies to influence initial planning decisions (Amekuzdi & Meyer, 2006).

The incorporation of sustainability and environmental justice or social inclusion in the planning process is not straightforward. It is necessary to develop methods and technologies to anticipate and measure the impacts of changes in transportation (Forkenbrock & Schweitzer, 1999). Planners must also understand the political face of these processes and how technical decisions are often inherently political decisions (Rosen, 2001; Hess, 2007).

This article contributes to an understanding of the political dynamics among parties in critical planning processes by looking in detail at *Transmilenio*, a comprehensive transportation system in Bogotá that is often described as the world's most impressive effort to modify urban transportation during the past decade. The first phase of the project affected 12% of the 7 million trips that take place daily in the city. As the next section describes, this change was critical, because it involved coordinating city agencies, private investors, and international suppliers, all in a climate of delicate political tension and uncertainty regarding how new technology would work in practice. Given these circumstances, all technical decisions impinging upon the overall project were actively debated, though in retrospect these outcomes were strongly influenced by political considerations structured by the power positions of the various stakeholders. The most interesting aspect of this account with respect to sustainability and environmental justice is that it demonstrates how new projects inevitably entail a good deal of financial, social, environmental, and political risk and ostensibly technical decisions can hide how—as well as to whom—the responsibility for those risks is assigned.

Case Background

The term *Transmilenio* designates three different entities: the government agency Transmilenio S.A. that manages Bogotá's transportation system; the long-term public works project *Transmilenio* that includes both public and private sector partners; and the infrastructure and functioning of the transportation system itself. As an organization, *Transmilenio* refers to the public agency that coordinates construction and maintenance of the infrastructure and manages contracts with the bus operators and money collectors, both of which are private sector firms. However, the term *Transmilenio* also refers to the agency's ongoing project, developed between April 1998 and December 2000 that has drawn on the expertise of engineers, economists, managers, and attorneys to design and implement an entirely new

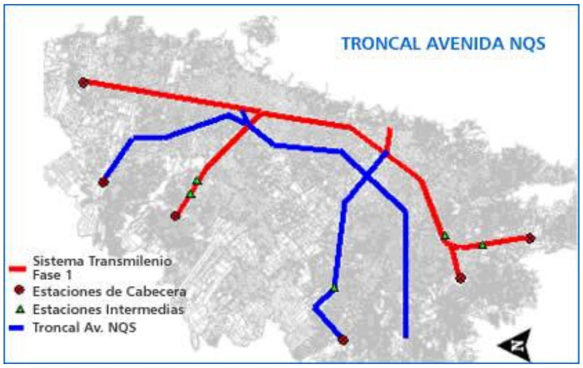

Figure 1 Phase 1 (red) and Phase 2 (blue) of the *Transmilenio* project in Bogotá *(Instituto de Desarrollo Urbano*, 2006).

technological system for Bogotá's main corridors. The plan involved various phases, of which only the first (Avenida Caracas, Avenida 80, and Autopista Norte) is at present fully completed. The second phase (Avenida Suba, Avenida Norte Quito Sur, and Avenida Américas) was still under construction in 2006, and subsequent stages have been planned with the goal of eventually having a system in which no point in the city will be farther than 500 meters from a transit stop (see Figures 1 and 2).

As infrastructure and technology, the term *Transmilenio* refers to the bus rapid transit design that separates public bus traffic from private automobiles and taxis and that provides passenger access via stations located in the middle of the roadway (see Figures 3 and 4). The body of the new, articulated buses has been completely reconfigured by teams of professional designers and engineers. In addition, the engines for the new buses feature state-of-the-art technology and the gearbox uses the latest transmission innovations to ensure smooth vehicle acceleration. The vehicles have a capacity of 160 passengers and an achieve an average speed of 28 kilometers per hour (kph) in contrast with the previous capacity of 80 passengers and average speed of 15 kph.

Transmilenio was conceived as a solution to the manifold problems of the city's existing bus system, known as the *transporte colectivo*. When *Transmilenio* was inaugurated in 2000, the 850,000 passengers that it soon carried represented only about 12% of the total daily trips on public transit in the city. By 2006, the *transporte colectivo* was responsible for approximately 64% of all bus trips in metropolitan Bogotá.[1] The still co-existing *transporte colectivo* bus system, based on private carriers, results in an excessive number of vehicles on the streets—approximately 22,000 when transportation

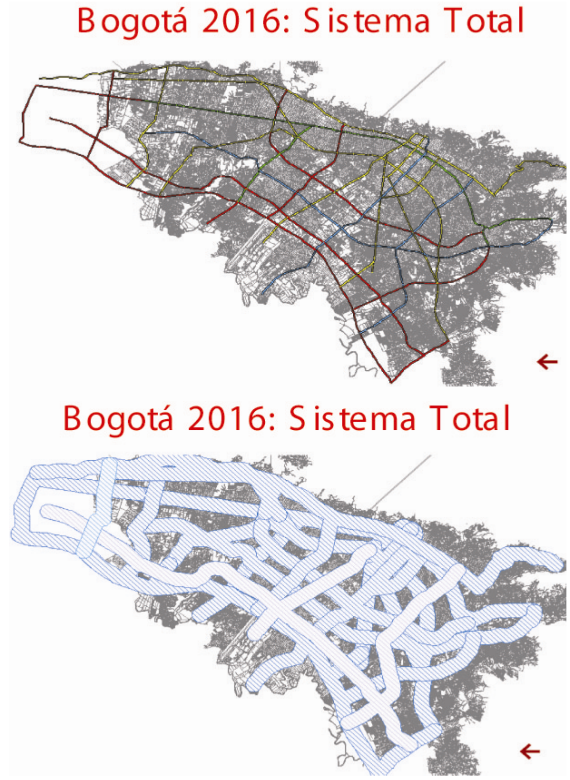

Figure 2 Routes (top) and coverage (bottom) within a 500m range when all phases are built and in operation (Sandoval, 2001).

planners deemed that only 8,000 are needed. The surplus buses create unnecessary air pollution and traffic congestion, and contribute to numerous traffic-related accidents and fatalities (see Figure 5).

The *transporte colectivo* system operates as follows. Passengers pay drivers directly for the trip and

Figure 3 Picture of the system to illustrate how the bus traffic is separated from private car, public taxi, and service traffic. Stations are in the middle of the road with access provided by pedestrian bridges (*Transmilenio*, 2004a).

[1] Private cars comprised 20% of the overall number of vehicle trips in the city and *Transmilenio* provided a further 16% (*Secretaria de Transito y Transporte*, 2002).

Figure 4 Conceptual representation of the *Transmilenio* System (*Transmilenio*, 2004b).

Figure 5 Authors' photographs of the streets of Bogotá showing how buses, taxis, and private cars operate in a mixed traffic situation.

drivers remit a share of this revenue to the bus owners. The vehicle owner then pays a bus company a fee for the right to drive on a specified route. This arrangement results in comprehensive but over-lapping coverage of the city, high frequency, intense competition, and passenger pick-ups at any point on the street rather than at designated stops. Although the system functions in a limited sense, it also creates numerous opportunities for corruption, especially among the regulatory bodies ostensibly responsible for establishing and enforcing the routes for the city's 68 bus companies. The advent of *Transmilenio* changed the underlying principles so that passengers paid their fares in the station rather than on the buses. Drivers were given a formal contract with the operating companies as well as schedules, uniforms, training, rest and lunch breaks, and other benefits (see Ardila, 2004).

The transition to the new system was critical because it implied a reconfiguration of the private companies that profited from the main corridors. Municipal officials were challenging an economic arrangement whereby private transit companies had been operating with little oversight for decades. Many of these operators had effectively captured the regulatory agencies, dampening any impetus for change. Nonetheless, the combination of forceful political support from a strong and popular mayor with a delicate and inclusive planning process directed by a skillful and prestigious strategist resulted in a successful transition (for a review, see Ardila, 2004). Furthermore, the planning, implementation, and operation of *Transmilenio* in Bogotá has attracted global attention because the project is the first comprehensive urban bus system. The general approach has come to be known as "high performance bus rapid transit." Prior to this project, transportation experts regarded heavy rail systems as the only viable technological approach for mass transportation on the scale available in Bogotá (Willumsen & Lillo, 2005).

The following analysis is based on a review of documents from the various public agencies associated with the *Transmilenio* initiative and interviews with ten planning officials involved in different aspects of the project. We also draw on personal knowledge of the *Transmilenio* bus system and professional experience working with engineers in Colombia. In accordance with standard practices within the sociology of technology, we assume that system-design decisions are motivated by a combination of both social and technical factors and that technical design elements are often aligned with broader political and social prerogatives (see, e.g., Bijker & Law, 1992).

Compressed Natural Gas, Petroleum, and National Energy Policy

It is fair to assume that the extensive organizational and technological innovation embodied by *Transmilenio* might have led to transition in the fuel source that would power the buses. After all, the fourth largest city in the country, Barranquila, had already demonstrated the viability of CNG as a fuel source for public buses by successfully operating a fleet of 4,000 vehicles outfitted with the necessary combustion equipment. This experience had resulted in the diffusion of considerable knowledge throughout Colombia regarding the use of CNG technology for public transit (*Ministerio de Transporte*, 2001). Bogotá also had a few stations that provided CNG, and many vehicles (mostly taxis) had already been converted to the less polluting fuel. By the late 1990s, other countries such as the United States already had experience in converting existing bus fleets to CNG (Hess, 2007).

Furthermore, changes in Colombia's national energy policy had to some degree facilitated conversion to CNG. In 1999, the government deregulated gasoline prompting a rapid price rise. In contrast, both diesel and CNG market regulation continued and their prices remained comparatively low. Under these circumstances, owners of public transportation vehicles, who had primarily used gasoline, began to convert their vans and buses to either diesel or CNG. Due to the location of Barranquila on Colombia's northern coast, within proximate distance of the first major commercial deposit of natural gas in the country and a coastal pipeline connecting the gas field to the city, it is here that the process of converting to CNG had progressed the furthest (see Figure 6).

Figure 6 Route of Colombia's first gas pipeline built during the early 1990s to connect the Ballena deposit in Guajira with Barranquilla and other coastal cities. Figure constructed by the authors based on an oil infrastructure map available from Ecopetrol S.A., 2005.

Colombia's newly discovered endowment of natural gas encouraged the government to actively champion the conversion of motor vehicles to CNG. However, the country is also a major oil exporter. Despite a drop in petroleum production during the 1990s, producers in the country were eventually able to improve the security situation and increase drilling to prior levels (United States Department of State, 2006). During this timeframe, the government pushed for CNG conversions, but did not offer incentives to facilitate the preference for CNG over diesel. In cities such as Barranquila that are located near natural gas resources, conversion tended toward CNG, but in much of the rest of the country the transition from gasoline followed the path of least technological resistance toward diesel, a process so extensive that it became known as dieselization. As a result, by the time that the *Transmilenio* project was under construction in the late 1990s, the general trend was toward diesel (Rodríguez-Padilla, 2002; Yepes, 2004).

By 2006, the CNG option was becoming more attractive as petroleum prices rose above US$60 per barrel and new public anxieties about peak oil gained credence, both in Colombia and at the global level. As Juan Baquero, a mechanical engineer with over 30 years of experience investing in transportation projects, explained:

> If Colombia had consumed more CNG, we would have been able to produce enough diesel for the country's needs, and we would even be able to export a surplus. Instead, today the whole country is extensively consuming diesel. Not only do we have to use all the local production, but we also have to import diesel at international prices. As a result, we are losing money.

If the national government had defined CNG as a national energy priority during the 1990s, the *Transmilenio* planners might have built natural gas into the project specifications. Instead, the contracts were written to allow individual bus companies to choose between CNG and diesel (*Transmilenio*, 2000). The ensuing agreements also specified that the city of Bogotá would not be legally obligated in the event that the new bus technology proved a failure. By not signaling a clear preference for CNG on either health or environmental grounds, and by shifting the risk of system failure (both in a technological and economic sense) onto the bus companies, the city set the stage for a choice in favor of diesel.

Risk and Diesel

The system designers for *Transmilenio* faced a number of problems that clearly shifted fuel preference toward diesel. First, they argued that the Barranquilla experience was not relevant because Bogotá's physical environment was distinctly different. Due to the city's high altitude (2,600 meters above sea level), the air has 21% less oxygen than it does at sea level. As Ricardo Wagner, a mechanical engineer with 35 years of experience designing engines, explained, "There was no experience in the world with a fleet of those features at the elevation of Bogotá." At the time, there were no articulated, two-body buses with a capacity for 160 passengers successfully operating in a city like Bogotá, not even in Mexico City, which has similar elevation and other conditions. Under such circumstances, the engineers were skeptical about using Bogotá as a test bed for CNG technology. As Jaime Loboguerrero—a mechanical engineer, professor, and entrepreneur—noted, "The Third World is always experimenting and paying the costs for others to benefit. We said, 'No,' we can't allow CNG to be the option."

More generally, there was concern that switching to an unproven technology, at least in the high-altitude environment, could wreak havoc on a complex urban transportation system and jeopardize the credibility of the *Transmilenio* project. There were also fears that the change would undermine plans to replace the existing system, an arrangement that was functional despite the chaos and corruption. As Juan Carlos Díaz, the first engineer involved in the project, commented:

> The system has to be reliable. In a mass transportation system that serves a city like Bogotá, with six or seven million inhabitants, it cannot be so fragile that it would stop at any given moment. That would generate a problem of public order that would threaten the functioning of the city.

Another consideration that favored diesel-powered buses was the scale of the change in a relatively short period of time. Given the size of the purchase, the contractors (private firms that owned and operated the buses under the coordination of the public agency Transmilenio S.A.) faced difficulties buying buses suitable for diesel fuel. For example, when attempting to acquire a fleet of articulated buses in Brazil, contractors found that the normal production quantity in 1999 was only eight buses per year. The required number of new buses in Bogotá for the year 2000 was 450 and the contractor that contacted the Brazilian companies had been tasked to acquire 160 functioning units. To shift to CNG, which had a much smaller market, would have only magnified the problem of acquiring the needed quantity within the planned schedule.

Due to the lower production levels of CNG buses relative to diesel, their up-front costs were higher. As a result, to be an attractive investment, the CNG buses had to offset their purchase price with lower costs of operation. One of the key factors in determining operating expenses is maintenance. As Juan Carlos Díaz commented: "The CNG providers argued that it was more economical, that maintenance was less expensive, and that the engines would last longer." Although the CNG manufacturers insisted that upkeep was lower for their buses than for diesel, the experience of Brazilian agencies that had been experimenting with CNG technology suggested that the CNG buses might also have higher breakdown rates. Víctor Raúl Martínez, the CEO of Si99, the largest and first contractor for *Transmilenio*, stated that a Brazilian colleague reported a higher rate of CNG failure events:

> The number of failure events of 60 CNG vehicles compared with another 60 diesel vehicles in the same route was much higher, making maintenance costs higher for CNG... Overall, the operating costs were also higher for CNG.

In 1999, Colombian banks were unwilling to lend money to the contractors who won the public competition and Si99 consequently ended up obtaining financing in Brazil. As a result, the negative Brazilian experience regarding maintenance for CNG buses became especially relevant.

In short, this combination of technical and financial factors created widespread uncertainty among the various engineers and bus companies involved in the system design. Resolution of the CNG-versus-diesel choice was exacerbated by the prospect of a major and unprecedented change in the city's underlying urban transportation infrastructure. Although the controversy was resolved by 1999, it may resurface in the future. Between 2000 and 2006, there was one experiment with a high capacity CNG bus in Bogotá, carried out by the contractor Transmasivo S.A. The performance of this vehicle has clearly been inferior to the ones powered by diesel, especially on steep roads. A *transporte colectivo* company (*Expreso Bogotano*) plans to test a fleet of 60 CNG buses between 2006 and 2008. Furthermore, during the next few years, a new CNG-powered bus rapid transit system will begin operationing in the nearby Peruvian capital of Lima. Colombia is also slowly deregulating diesel prices, which have been rising relative to CNG. This convergence of factors may ultimately trigger a reevaluation of the efficacy of diesel in Bogotá. Furthermore, the *Transmilenio* project is set up to permit experimentation and to provide for ongoing turnover of buses. These features provide the resilience that may allow for overcoming past missteps—that is, of course, if the diesel choice ends up being considered a flawed decision (Newman, 2005). To put it another way, the constellation of factors that configured diesel as the least risky choice in 1999 is changing and by 2008, when all of the buses that were part of the first phase have to be renewed, a different arrangement of variables might tilt the balance in favor of CNG.

Discussion and Conclusion

The CNG-versus-diesel controversy in Colombia articulated two different types of risk. At the outset, we noted that a city-council member defined the problem as choosing the vehicle design and fuel that would produce the least pollution, regardless of costs. This view expressed risk from the perspective of the general public and prioritized the protection of human health and the environment. This approach is consistent with the precautionary principle in emphasizing adoption of the safest technology in the face of known and unknown health risks.

However, if we follow the city's contracts, municipal officials did not stipulate that the contractors should develop a system that would generate the lowest level of health and environmental risk. Rather, these agreements achieved the opposite outcome, leaving the decision over fuel and bus technology up to the contractors and also shifting technological and financial risk onto them. From the perspective of the engineers and managers who designed the system, there was too much technological and financial uncertainty to warrant a shift to CNG, even if it was the cleaner fuel option at the time. If the private sector partners were going to shift to CNG, they would have to absorb on their own the projected higher costs, as well as the risk of potential failure. As Víctor Raúl Martínez of Si99 commented, "There is a fundamental unanswered question: if CNG vehicles are more expensive, and their operation and maintenance costs are also higher, who is going to pay for the higher costs?" Because the local government did not specify that it wanted a targeted level of emissions reduction, the issue of which technology was cleaner disappeared from the decision-making process. It is not entirely clear why the municipal officials did not define a specific emissions-reduction target. Our most plausible explanation is that when the contracts were issued environmental concerns were a less prominent policy issue than they are today and any heightened public health risk associated with transportation was perceived to result from traffic accidents.

One general conclusion from this case study is that a government intent on cleaning the air and promoting public health cannot presume that its private partners, when given a choice, will select the least polluting technology and absorb the costs and risks of implementing untested alternatives. Under such circumstances the private sector partners are likely to select the least risky and most profitable options and to justify them as environmentally acceptable. In other words, the lack of cost and risk buffering by public authorities invites the private sector partners to ignore the public risk of air pollution and to give singular preference to its own priorities. To encourage the adoption and diffusion of new technologies, governments need to incorporate health and environmental standards into the system-design specifications (such as clearly mandating acceptable emissions levels for new buses), and then they need to create contractual arrangements that fairly distribute financial costs and technological risks of implementing new socio-technical systems.

Under this scenario, the government establishes the system standards and the private sector firms decide which alternatives offer the lowest technical uncertainty and financial risk toward achieving these targets. We recognize that the ideal division of labor between public agencies and their contractors is not as easy to implement as it might first appear. In many cases involving innovative technologies**,** the optimal alternative is often not transparent. The CNG firms claimed that their technology was cleaner, but from a technical and operational perspective the emissions issue was much more complicated. As Jaime Loboguerrero, one of the engineers in charge of testing the vehicles, pointed out:

> CNG engines have a very good range of operation when correctly calibrated. Under those circumstances they contaminate the air less than diesel. Conversely, diesel engines that are correctly calibrated pollute less than CNG engines that are not properly calibrated. Furthermore, diesel engines are more forgiving of calibration errors than CNG engines.

Because the technical issues surrounding system selection remain unresolved, municipal officials are not able to solve the problem engendered by uncertainty by defining an acceptable level of public risk (in the form of emissions standards) and then leaving implementation up to the experts. Instead, in cases where the technology is complicated, in flux, or subject to controversy, government may also need to intervene by mandating at least some design features. This is exactly what happened in the case of *Transmilenio*. Once it became apparent that diesel was emerging as the preferred fuel choice, municipal officials added a contract provision stipulating that the new buses must have catalytic converters. However, this decision immediately became enmeshed in the technological debate. In Colombia, the sulfur content of diesel is about 3,000 parts per million (ppm), whereas Euro 2 diesel engines are designed for 500 ppm and Euro 3 engines for 50 ppm. As Víctor Raúl Martínez of Si99 recalled,

> I remember that there was a disagreement between the president of Mercedes-Benz and the head of the Environmental Agency of Bogotá regarding the contractual requirement that mandated catalytic converters in the buses. Mercedes-Benz, Scania, Volvo, and other manufacturers have their own laboratories that do precise and reliable tests. They argued that to install catalytic converters in buses with engines at a Euro 2 standard and with a fuel that had more than 600 ppm of sulfur was useless. We finally installed the converters, but we do not think that it really helped in any way...Instead of requiring all buses to have a catalytic converter, we feel it would be better to ask the Colombia Petroleum Company to produce better diesel by upgrading the refinery in Cartagena or elsewhere.

Although it could be alleged that municipal officials in Bogotá failed by mandating the use of catalytic converters rather than both catalytic converters and ultra-low sulfur diesel fuel, we submit that they were actually on the right track. A consistent approach to the negotiation of public and private conceptions of risk would need to involve two stages—first define an acceptable level of pollution and then determine the technologies that are needed to meet the standard (e.g., particulate traps, catalytic converters, low-sulfur diesel, or even a non-diesel fuel such as CNG) rather than leave the second part of the decision up to private sector partners. It is possible to construe Bogotá's Environmental Agency as having failed only to the extent that it did not understand the complexity of the interface between the design of the technology and the various risks to human health and the environment. Yet, in situations where the experts do not agree, or in instances where they may be biased in favor of existing systems, the public partner needs to step in and take a position on the technological controversy. Government planners cannot simply draw a line demarcating an acceptable air quality or emissions standard and then expect system designers and contractors to resolve outstanding discrepancies over relative performance. They need to be able to articulate both an acceptable standard of air quality and an appropriate technological system to meet that goal. Once these dual objectives have been clearly stated, the private sector partners can develop proposals that provide the desired capital and services based on their own appraisals of the underlying financial and technological risks.

Acknowledgement

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COMMUNITY ESSAY

Implementation of the MediSend Program: a multidisciplinary medical surplus recovery initiative at an academic health science center

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Biruh Workeneh's Personal Statement:

As a second year medical student my focus was narrowly on navigating and absorbing the enormous amount of information that I needed to pass my courses—it was not one year at a time, rather it was one course at a time. This changed when I became a student leader and met phenomenal individuals, like my co-author, who introduced the idea of medical surplus recovery to me, as well as Martin Lazar, who founded MediSend/International. The world was not simply going to wait while I struggled to finish medical school, and if I wanted to make a difference I had to jump in. In the article below we describe the MediSend Program, a student-conceived, student-driven effort to collect medical, dental, and educational surplus at the University of Texas Health Science Center at Houston. The students that helped and continue to help craft the MediSend Program have realized that they are not only important constituents of higher education, but they play a vital role in shaping university priorities. In the process, the MediSend Program has provided an uncommon learning experience, one that incorporates the values of compassion and altruism with environmental preservation and equitable resource distribution. I am no longer a student and consider my participation in sustainable solutions a *duty*, a sensibility that was shaped during my tenure in medical school. Sustainability should be a universal guiding principle in healthcare education and practice, as well as other disciplines, because it is the key to human survival.

Introduction

There has been increasing emphasis in health professional education and training to incorporate interdisciplinary collaboration into curricula, research, and practice. However, these efforts frequently do not develop support mechanisms that foster sustainable interactions between disciplines and therefore do not continue. The MediSend Program, a medical surplus recovery initiative that originated among Texas Medical Center students and was officially launched in 2002, exposes students, faculty, and administrators from various disciplines to resource management and environmental conservation values vital to a sustainable healthcare system. The MediSend Program acts to instill an institutional culture of humanitarianism and environmental conservation as students and faculty from various disciplines participate in this effort from year to year.

An important and largely under-recognized consequence of escalating healthcare spending is the enormous medical surplus that is generated and discarded. The annual price tag for this surplus in the United States is estimated at US$6.25 billion and the cost of storage and disposal alone represents a significant portion of healthcare expenditure (Levit et al. 2002). In addition to abating the financial outlays involved in storing and disposing medical surplus and the burden it imposes on the environment, medical recovery serves a humanitarian function, benefiting developing countries in desperate need of medical supplies.

A handful of organizations within the United States, including Recovered Medical Equipment for the Developing World (REMEDY) at Yale-New Haven Hospital, Project Hope, MediSend/International, and MedicalBridges, have successfully networked with hospital systems to collect and distribute surpluses to selected recipients across the world (Crone, 1992; Rosenblatt & Silverman, 1992; 1994; Rosenblatt et al. 1993). However, these efforts primarily involve health professionals as participants in recovery efforts and have yet to effectively integrate students at their most formative stages of health professional education and training.

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The MediSend Program bridges health education and medical recovery in a multidisciplinary university-based research center, the University of Texas Health Science Center at Houston (UT-Houston), which is comprised of schools of medicine, dentistry, public health, nursing, biomedical sciences, and health informatics. Students working through the student governance body at UT-Houston developed over a two-year period a proposal to recover medical, educational, and research surplus. Several benchmarks provided the foundation and context for facilitating its eventual implementation.

Institutional Benchmarks

Environmental Sustainability

In 1996, UT-Houston embarked on a course to incorporate environmental sustainability into its operations and strategic plan and this resolve was implemented by the creation of a well-staffed sustainability office. This commitment entailed a comprehensive effort to reduce use of resources, dependence on fossil fuels, and production of persistent human-made compounds that are not environmentally stable or safe. New buildings are now being designed in accordance with this vision and architectural goal, while existing facilities incorporate alternative energy sources and reclaimed and recycled materials (e.g., solar energy and discarded flooring materials). Further promoting environmental sustainability, the university adopted the Natural Step, a relatively new organizational philosophy that encourages harmony between business and the environment (Broman et al. 2000). The MediSend Program is consistent with Natural Step principles, extending the life of medical supplies and equipment by making them available to regions where these items are scarce and medical technology is underdeveloped. The sustainability office also provided the institutional infrastructure and operational assistance for the MediSend Program as it was being developed.

Interdisciplinary Education, Research, and Practice

A historic meeting occurred at UT-Houston in 1994 when the leaders of the American Medical Association and the American Public Health Association met for the first time and launched the Medicine/Public Health Initiative (MPHI), a collaborative partnership between the two disciplines to work together for innovative solutions to health issues (Reiser, 1996; 1997; Cashman et al. 1999). MPHI has invigorated interest in interdisciplinary education, research, and practice not only between the medical and public health schools, but also among other UT-Houston schools. Interdisciplinary programs have been implemented and promoted despite fundamental administrative and logistical challenges that exist at an urban campus with six component schools. Noteworthy programs include Frontiers in Health, a problem-based learning course offered to all enrolled students; Houston Outreach, Medicine, Education, and Social Services (HOMES), a student-run clinic for the homeless that incorporates a team-based approach to healthcare delivery; and an annual healthcare competition with interdisciplinary teams of students from all six schools. A competitive medicine/public health fellowship challenged students from all component schools to develop strategies for various health fields in reshaping education, research, and practice. The MediSend Program was launched by a pair of students who participated in the fellowship program at different schools, suggesting the value of such efforts.

MediSend/International

Founded in 1990 as a non-profit organization, MediSend/International collects medical supplies, instruments, and equipment no longer used in the United States and distributes them to public and charity hospitals in developing countries (MediSend/International, 2006). Donated supplies from hospitals, clinics, agencies, and individuals are sorted, inventoried, and shipped in response to requests from prequalified charitable institutions abroad that offer medical care. UT-Houston and MediSend/International have forged a strategic partnership to send medical surplus.

Model for an Institutional Program

A group of student leaders in 1999 originated the proposal for the Medical and Educational Surplus Recovery Initiative (MediSend Program) at UT-Houston. The program's institutionalization was critical to ensuring project continuation after graduation of the original student cadre. Figure 1 depicts the MediSend Program's chronological development, which may serve as an institutional model for other universities. Although the activities are shown as sequential or linear, in practice much development and implementation was conducted simultaneously. A faculty and administration advisory committee was created as program design was finalized after initial feasibility research. A MediSend Office, established as a part of the university's existing sustainability program, was created to oversee the MediSend program and to serve as a liaison between the university and MediSend/International. Additionally, the university committed US$25,000 yearly to a fellowship program to provide ongoing analysis and institute a research component into the sustainability effort.

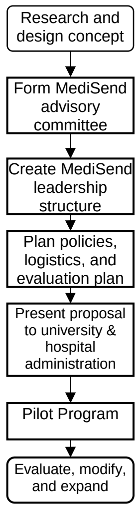
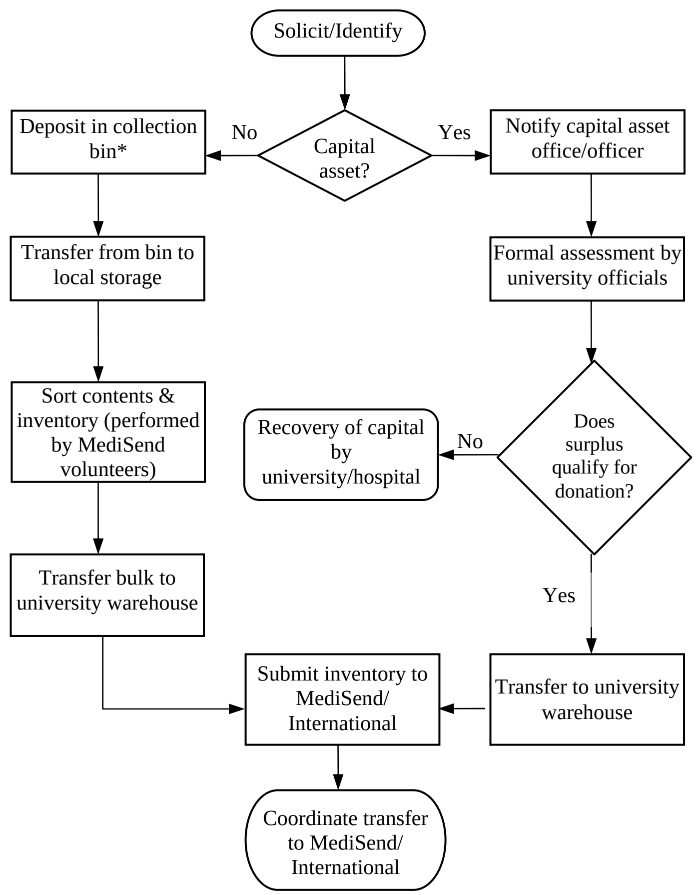


Figure 1 Organizational development.

Several ethical and legal concerns had to be addressed before the program could begin. As a state-funded institution, UT-Houston has a mandate to internally reclaim all usable items, or to otherwise identify local public entities to which the surplus could be offered. According to these policies, the university is prohibited from directly donating to foreign countries, but a provision allows for donations of surplus to charity and nonprofit organizations. Therefore, once MediSend/Internation-al acquires the donated surplus, the university is not involved in selecting recipients and is thereby effectively removed from this restriction. Items deemed not suitable for donation to MediSend/International because of efficacy and safety concerns include pharmaceuticals, liquids, or unpackaged sharp objects.

Before initiating the program at other UT-Houston schools, student leaders selected the dental school, where the university has full control of acquisitions, capital assets, and supply disposition, for a pilot program. Figure 2 is a generalized flowchart for the collection of surplus on which items are classified as capital or noncapital assets, with capital assets having value greater than US$1,000. Students and faculty have the greatest role identifying potential noncapital surplus and developing a procedure to collect the material. Noncapital assets are collected by placing receptacle bins at strategic locations for partially used clinical supplies such as opened gauze packages, incomplete dental burr sets, and expired or surplus items that do not meet the definition of capital assets. Student volunteers monitor the bins and notify custodial services to remove the contents and transfer the material to a centralized storage location. The students periodically sort, select, and inventory the collected surplus before the items are transferred to an off-campus warehouse. Students and faculty may also identify capital assets for donation; however, these transfers follow the university's formal procedures and involve the capital assets management office.

Students were involved in the planning and design of the recovery initiative and incorporating it into the university's operations. To date, the pilot program has collected over fifty large (4.5 cubic feet) boxes of dental supplies and over 1,000 medical books and journals. In 2002, the program facilitated the donation of books worth US$500 to a medical school in Da Nang, Vietnam. More recently, UT-Houston and the student leadership have expanded the program to include Project Cure and are evaluating other organizations that can model the relationship between MediSend/International and UT-Houston. The full evaluation and benefits of this recovery program are still several years away; however, stu-



*Campus-wide awareness program put in place encouraging medical professional students to identify and place recoverable items into designated bins.

Figure 2 Recovery Procedures.

dents, staff, faculty, and administration have under taken the initial steps in launching a pilot program.

Conclusion

Universities recognize that training physicians, dentists, nurses, and scientists seek creative and meaningful ways to enrich their education and prepare themselves for practice in a world that is vastly different from the one of their predecessors. As part of health professional education, institutions of higher education should recognize their role in student socialization and aim to produce health professionals more compassionate in their work and environmentally responsible within their communities. The MediSend Program has already proved an effective model, fostering similar relationships with other nonprofit organizations at UT-Houston. We believe similar programs at other universities and health science centers can model what was accomplished at UT-Houston and introduce a valuable learning experience for many health science students regardless of discipline.

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COMMUNITY ESSAY

Developing a sustainable water-delivery system in rural El Salvador

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Michael Wing's Personal Statement:

Engineers Without Borders-USA (EWB-USA) consists of over 50 professional chapters throughout the country and over 100 student chapters at engineering universities. The goal of EWB-USA is to assist developing communities implement sustainable engineering projects that foster quality-of-life improvements while developing internationally responsible engineers and engineering students. An EWB-USA chapter at Oregon State University (EWB-OSU) has focused efforts on designing a sustainable water system to provide clean water for two communities in El Salvador. The communities are located in remote and mountainous terrain and have little available data describing local resources. The health of the communities has suffered due to a lack of clean drinking water. Small teams from the EWB-OSU chapter have now twice visited the communities to collect data using global positioning system (GPS) receivers. Financial support for travel costs has come from a variety of sources. The local community has helped field teams locate important resources and verify information to support the design process. Although considerable project progress has occurred, challenges have resulted from working in remote and rugged landscapes and also from land use and ownership considerations in the communities. We describe in this essay EWB-OSU activities to design and implement an engineering project to provide freshwater to rural communities in a remote, rural community.

Introduction

Engineers Without Borders-USA (EWB-USA) originated in 2001 at the University of Colorado at Boulder and is a member of EWB International (Amadei, 2004). Dr. Bernard Amadei, a professor of civil engineering, learned that a village in Belize needed access to freshwater to improve living conditions for local inhabitants. Amadei formed a group of student volunteers and, in collaboration with a professional engineer, designed a sustainable solution for providing freshwater to the community. The success of this effort encouraged Amadei to launch EWB-USA. Over 100 student and more than 30 professional chapters have since formed, with new chapters forming regularly. The primary goal of EWB-USA is to help developing communities implement sustainable engineering projects that improve quality of life while fostering the education of internationally responsible engineers and engineering students. The majority of projects undertaken by EWB-USA chapters involves supplying water to rural communities, although other initiatives have addressed energy, transportation, and food-production issues.

Students at Oregon State University (OSU) established Engineers Without Borders-OSU (EWB-OSU) during the spring of 2005. A Peace Corps volunteer in El Salvador asked EWB-USA to assess the feasibility of implementing a potable water-delivery system for the communities of El Naranjito and Las Mercedes. EWB-OSU applied for and was ultimately granted the project by EWB-USA. The Peace Corps volunteer represented an *Asociación para el Desarollo Comunitario* (ADESCO), a group of community members devoted to the development of El Naranjito and Las Mercedes. ADESCOs are common in Central American villages as a means for community members to cooperatively bring in developmental assistance for their locales.

The El Naranjito and Las Mercedes communities reside in the northwest region of Ahuachapán, El Salvador (Figure 1). The area is rural, mountainous, and isolated. Women and children walk long distances daily to gather water and residents subsist on local farming and low incomes (less than US$70 per month) from work on nearby coffee plantations. Illness from water-borne pathogens and parasites is a constant threat to village members. Local children are undernourished and often suffer from diarrhea and

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Figure 1 Central America and El Salvador.

other ailments caused by drinking unclean water. Several natural springs are located within community boundaries, but, given the large geographic extent of their surrounding vicinity—approximately 16 square kilometers (km) of mountainous terrain—access is challenging and time consuming.

With only a general description of the region available, EWB-OSU began assessing the feasibility of a sustainable water-delivery project. The plan would need to be designed through "appropriate technology," such that community members would be encouraged to take responsibility for the system and its upkeep (Hazeltine & Bull, 1999). EWB-OSU required information regarding community locations and basic topographic measurements for the feasibility assessment. Necessary data included housing sites, transportation networks, spring source and distribution locations, community-meeting places, and schools. Having accurate and reliable measurement information was essential, not only for identifying potential solutions and their feasibility, but also for eventual project design and implementation. There were many potential solutions to providing a sustainable freshwater-delivery system, requiring varying types of water pumps, filtration systems, and general water-routing infrastructure depending on the particular intervention. Few data were available given the remoteness and small size of the communities. Although EWB-OSU found a coarse scale topographic map, it was over 20 years old with uncertain information regarding the villages and surrounding landscapes. Community knowledge was necessary to help locate features of interest to the project.

Previous studies have used a process known as participatory mapping to help locate community resources in developing countries (Duvail et al. 2006; Shrestha, 2006). Participatory mapping involves local residents in externally sponsored projects by encouraging direct engagement in the creation and management of maps or spatial databases. Participatory mapping seeks to recruit people to identify features of interest and to locate or verify the specific positions of these sites on hardcopy and digital maps. This collaborative approach to documenting community resources became widely recognized for encouraging effective participation during the early 1990s and has since been extensively used in natural resource applications and in many other disciplines (Chambers, 2006). Participatory mapping is also sometimes described as participatory geographic information systems (GIS) and can include many different types of geospatial information including hand-drawn maps, aerial photographs, satellite imagery, and GPS. Participatory mapping attempts to use the expert knowledge of community members regarding resource locations and resource-use history. This methodology can also involve residents in decision-making processes and encourages community empowerment and innovation (Rambaldi et al. 2006).

Due to the lack of available data and the need to engage the community in identifying key water and other local resources, field visits were required to collect location and topographic data. Field crews would have limited time to collect data and would face landscape and equipment challenges in assembling information efficiently. After evaluating several alternatives, EWB-OSU selected mapping-grade GPS receivers as the most viable option for collecting measurements of community resources. The use of these GPS receivers has encouraged community support for the overall project.

Working in remote and rugged landscapes poses unique challenges for providing potable water resources. In addition, land-use patterns, ownership holdings, and other societal considerations further complicate project efficiency. This article describes how EWB-OSU designed the water-delivery project and the group's progress moving toward implementation.

Data Collection Team Preparations

Faculty advisors and student officers selected several EWB-OSU students and a practicing engineer from the EWB Portland professional chapter to travel to the El Salvadoran communities for the initial data collection in March of 2006. Project requirements would involve locating and measuring the elevation and horizontal positions of existing springs, villages, transportation corridors, and other relevant infrastructure over the 16 square km study area within approximately five days. Both professional and student members rely on funding support for participation in EWB projects. The financial resources for student involvement was provided initially by a combination of fund-raising efforts such as bake sales, international dinner fundraisers, and OSU athletic event assistance. Additional support for student-travel costs came from individual donations, the OSU College of Engineering, and the OSU Foundation. Specific requirements for the students included Spanish proficiency and previous international travel experience. In addition, students from different engineering disciplines were included to ensure breadth of expertise.

Mapping-grade GPS receivers were selected as the data-collection tool for the field visit due to their compact size, relative ruggedness, and measurement accuracy (typically 1–5 meters horizontally) with differential correction of field data collected under forest canopy (Bolstad et al. 2005). Trimble Navigation, Ltd, an established manufacturer of mapping-grade GPS, agreed to provide the data-collection team with two GPS receivers. The choice of a mapping-grade GPS receiver for data collection offered several advantages over other potential equipment. Its small size is easy to manage; it is lightweight when compared to traditional survey equipment; and it is convenient to manipulate in the field. It is also possible to learn to operate the receiver in several hours and accurate measurements can be taken by following a few basic protocols. Also of significance, the system can create spatial databases of resource features as they are collected, a capability that enabled the creation of a large hard-copy map for use during a participatory mapping session with community members.

Initial Site Assessment

EWB-OSU had several goals for the initial site-assessment trip to El Salvador: build a community relationship, observe the basic health of residents, and collect baseline GPS data related to supporting water delivery-system infrastructure such as water tanks, water-source points, and major roads. Pursuing these goals would provide familiarity with community members, pressing local issues, and regional geography, while also generating baseline data to be analyzed for the project-feasibility analysis.

While in El Salvador, the four group members on the data-collection team spent considerable time visiting homes and meeting residents, asking community members to help identify water and other resource locations, and answering questions about the group or project objectives. While conducting their visits, the team collected GPS data, making sure to include major infrastructure such as schools, churches, and water-related resources. The team eventually used the data to create a community map during its site visit that included trails, springs, and major landmarks. Team members frequently returned to trails they had traversed earlier to assure data consistency. Each subsequent pass closely followed previously recorded data.

Hydrographic features, such as streams and springs, were among the most challenging features to measure with the GPS receivers. Water naturally follows the easiest path downwards due to gravity and, as a result, many watercourses are located in small ravines or valleys that branch off of the main mountain ridge. Thus, a large portion of the required data was for sites that had low satellite visibility and sometimes none at all. Satellite visibility was reduced primarily by the small ridges themselves, but also by the forest canopy that grows in these ravines due to the presence of water. If an insufficient number of satellite signals was received when standing directly over a feature, the data collector would climb to a location that allowed satellite communications and measure an offset distance and elevation difference from the desired data point.

Fostering Community Involvement

While the field team conducted home visits and recorded the locations of trails and springs, community members inevitably took an interest in the GPS receivers. While collecting data at a spring, the team would frequently encounter children. The youngsters were usually quite shy but nonetheless curious about the field-team members walking around poking at a “yellow block” (our GPS equipment) with a pen. Several people asked how the features on the GPS-receiver screens were being created and seemed to have at least a rudimentary understanding of satellites, perhaps through familiarity with cell-phone technology. Some of the residents understood that the GPS receivers were communicating with satellites and using a set of calculations to measure and locate community features.

Near the end of the visit to El Naranjito and Las Mercedes, the EWB-OSU representatives were invited to an ADESCO-led community meeting. During the meeting, the team presented some basic information about the chapter and its plans to design a sustainable water-delivery system. Over 60 community members attended the meeting, a record turnout according to the local Peace Corps volunteer. The team had created a rough map of the communities and water-related resources from the data collected on the GPS receivers during the week. The map was drawn and scaled onto a large piece of paper and community members were invited to comment on it. Villagers were able to indicate population distributions, important information when considering potential water-distribution sites and access. Additionally, residents identified several water sources that EWB-OSU had not visited or known about (Figure 2).

Figure 2 Community members interact with OSU-EWB members in El Salvador.

The map had a strong effect on the community. Only two area maps had been previously located and both of them were at coarse scales. Furthermore, due to limited opportunities for formal education, few residents had even seen a road map before. However, some meeting participants caught on very quickly and made helpful contributions, suggesting local resources to include on the map. The map helped many people understand the purpose of the "yellow blocks" and demonstrated the EWB-OSU team's interest in the community, contributing to one of the team's primary goals: to build relationships with residents and engage them in assisting with the project. The map caught the attention of the community members, encouraged them to contribute data, and helped them to visualize improvements in their well-being.

Upon the team's return to the United States, data from the GPS receivers were processed and used for initial design analysis. This information was also integrated with the census-style geographical inputs that had been gathered from the community. GPS-processing software was used to output the data, complete with elevation measurements for mapping and analysis applications. Additionally, students converted a topographic map of the study area that had been obtained from the *Geogragrafico Nacional, Ministerio de Obras Publicas* into a digital format. The map was at a published scale of 1:25,000 and contained details on transportation infrastructure, hydrological resources, and population centers. GPS-collected coordinates that could be associated with prominent features on the digital map were used to produce a geo-referenced database for input into a GIS. The GPS-collected positions were then overlaid on the topographic map in a GIS so that both data sources could be compared. The two data sources agreed in general about the location of roads and villages (Figure 3). Topographic maps are typically created from aerial photography, a technique that generally results in varying levels of data quality. Larger features, such as major transportation or river networks, will often be better represented than secondary roads or trails in the final product. Nonetheless, GPS measurements created using the data-collection protocols followed in this study should be more accurate than most features on a 1:25,000 scale topographic map (Oderwald & Boucher, 2003).

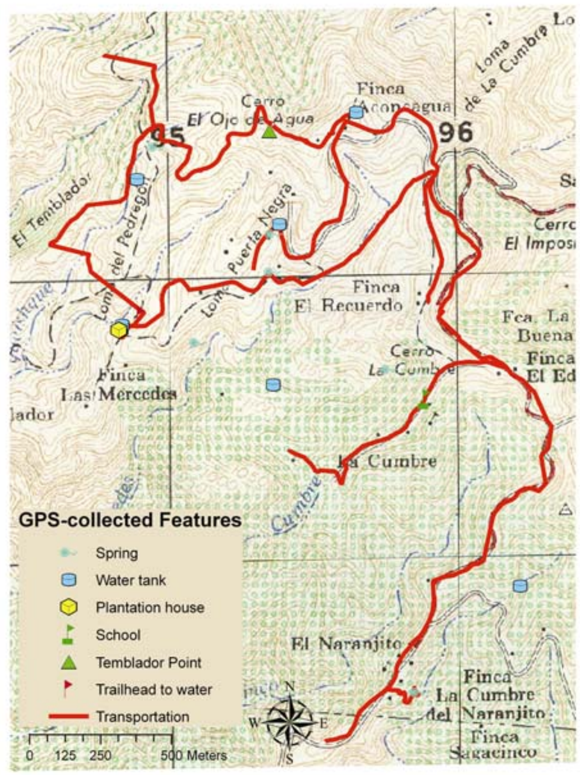

Figure 3 GPS-collected positions plotted on a 1:25,000 scale topographic map.

The processed field data have also been essential in formulating solutions for supplying safe water to the Las Mercedes and El Naranjito communities. The visual site assessment and analysis of the data gathered during the first team visit revealed that the geographic extent and distribution of homes was greater than had been expected, making a single solution for all local inhabitants impractical. The site- assessment team identified several potential locations for initial

Table 1 Evaluative matrix used to prioritize potential water-delivery projects.

	Dam at El Naranjito	Los Patios tank renovation & gravity-feed pipes	Los Patios tank renovation & wash/treatment station	Several large rain water-storage tanks	Individual rain water-storage tanks	Stream pumps
Capital cost	3	4	5	1	1	1
Maintenance cost	4	4	3	2	4	1
Ease of use	4	5	2	4	3	2
Construction ease	3	2	5	1	2	1
Chapter feasibility	3	4	5	1	2	1
Sustainability	4	2	4	3	3	2
Score for # homes/people	2	1	4	4	5	4
Total (higher is better)	**23**	**22**	**28**	**16**	**20**	**12**

water projects (Table 1). These proposals were subsequently analyzed through an evaluative matrix that included the number of homes or people that would benefit, environmental impacts, feasibility/constructability, economic factors (i.e., implementation cost), and sustainability features (i.e., long-term costs to the community).

Each of the seven evaluation considerations received a score between one and five, with five indicating the highest potential. Scores were initially based on the perceptions of the site-assessment team and later fine tuned during EWB-OSU meetings. Although the matrix resulted in seven numerical scores and a summary statistic for each possible water-delivery project, the evaluations weighed some considerations more heavily than others. For example, maintenance and sustainability carried a greater weighting than other factors. These issues were judged to be more important since they would more significantly influence the long-term success of any water-delivery project. The methodology also weighted most heavily the number of homes or people that would benefit. In addition, although the scoring system included subjective criteria, the matrix made possible a relative comparison of project parameters. EWB-OSU decided on which projects to pursue by comparing the leading summary scores and the individual tallies of the more heavily-weighted factors. As a result, three primary projects were selected: the El Naranjito school (which does not currently have a water source) and two clusters of homes. A second site assessment was subsequently planned to collect more detailed information in preparation for water-system design at these locations.

Second Site Assessment

Several EWB-OSU students and two engineers from a professional EWB chapter visited El Salvador for the second site assessment six months after the initial visit. Unexpected issues arose with regard to land ownership and usage permissions during this subsequent trip. The region surrounding El Naranjito and Las Mercedes is mainly dedicated to coffee cultivation, with farm owners controlling large portions of the landscape. During the first visit an unused tank connected to a year-round stream had been verbally confirmed for drinking-water storage at one of the primary project sites. However, the owner eventually disapproved, wanting to instead reserve the site for possible coffee processing. In addition, the assessment team noted that economic, ownership, and landscape constraints would limit opportunities not only for constructing large holding tanks, but also for locating reliable water sources that could adequately supply them. A conservative average water-use figure of 150 liters per day per home would result in a total volume of 1,095,000 liters for the year for each group of 20 homes. Even if half of this volume were stored in a tank, the tank's dimensions would be prohibitive in terms of cost and construction because of silty clay soils and relatively high local seismic activity. Finding level terrain for building would also be challenging under these conditions.

Given these findings, the site-assessment team decided to develop new approaches for providing water. Conversations with residents revealed that a three-month dry season was the critical period in which community members had to travel farthest to find water. As a result, the installation of holding tanks with the capacity to catch rainwater for use during the dry season was identified as a potential solution. Average rainfall data and an estimated water demand of 150 liters per home per day were used to calculate the water volume necessary to provide water for 20 homes during the dry season. These measurements were also used to determine the minimum surface area of the tank that would be required to catch the critical water volume.

A GPS receiver was again used during the second site assessment to map key landmarks in the areas that seemed viable for building a tank. The team also identified trees, infrastructure, and slope characteristics for these areas to help further evaluate locations for design and relative distances to homes. Site visits and mapping revealed that potential tank locations at higher elevations were often difficult to access. The distribution of residents in the region tended to corresponded closely with a series of ridges that extended radially from centralized hilltops on which signal towers were built. The signal towers service the surrounding region for radio, cell phone, television, and military communications. The GPS receiver also mapped a power station adjacent to the signal towers that may be of further interest if the design requires electricity.

Design Process

Recent project efforts since the second site assessment have involved designing water-delivery systems. Because some uncertainty remains as to which locations will receive landowner permission to build, two separate sets of infrastructure are being designed: a rainwater-catchment tank and a high-head low-flow pump system. The rainwater-catchment tank would need to hold 270,000 liters with a surface-catchment area of at least 176 square meters to provide sufficient area to fill the tank during the winter months. The tank would provide water for approximately 20 homes in the community. Another tank could be built in a different area to provide water to another 20 homes in the community during the dry months. The high-head low-flow pump system would carry water from a perennial spring to a higher-elevation centralized distribution point so that a small tank (about 30,000 liters) could be accessed throughout the year. Given the seismic activity of the region, students with structural engineering coursework, along with professors and professionals with relevant expertise, will also be involved in infrastructure design.

Water filtering will be necessary to address human-health issues among community residents. Consequently, EWB-OSU has interacted with Potters for Peace, an international organization that uses regional materials and clay mixtures to mix and fire clay pots. The pots have small small grains of flammable material that ignite during firing and form tiny channels that result in a water filtration rate of two liters per hour. The filters are then submerged in a colloidal silver mixture that kills coliform and microbacteria. The working life of the colloidal mixture is at least two years. The filters are made locally by a solidarity program in a San Salvador factory that the second site-assessment team visited. EWB-OSU is planning to implement the distribution of clay filters to families who commit to paying US$0.33/month to replace the filter every two years. A recent fund-raising banquet held on the OSU campus has also gathered financial support to subsidize costs for Potters for Peace.

To finalize the infrastructure designs, EWB-OSU will require some additional information—including the topography of water-delivery paths and a more detailed geotechnical site exploration of potential areas for water tanks—to assess soil-bearing capacity and slope stability. In addition to these empirical data, an assessment of spring-water quality and potential watershed impacts must be carried out since the effects on downstream users and communities may have political consequences. Las Mercedes and El Naranjito are also adjacent to a large national park (*Parque Nacional El Imposible*) for which ecological conditions are a concern. EWB-OSU environmental engineering students and environmental and sustainable design professionals will be involved in this aspect of the work. Consultation with groups that have previously studied *El Parque Nacional El Imposible*—including local non-governmental organizations and representatives from the national university—will also assist in this evaluation of potential ecological impacts.

Conclusion

EWB-OSU's assessment visits and the involvement of community members in identifying water-resource solutions have resulted in the creation of baseline community-resource data and progress developing a sustainable water-delivery system. Although initially proposed projects had to be modified in light of landscape characteristics and land-ownership considerations, headway continues to be made toward meeting the needs of the two subject communities. Regardless of the final design, collaboration will be necessary so that residents will be encouraged to take ownership of the infrastructure over the full course of its lifecycle. As planning progresses for the water-delivery system, the team will request input from the community regarding preferred locations, systems, and monthly costs that each family would be willing to pay. Once the designs reach the preliminary sketch stage, the community will then be contacted again for input before materials are ordered and construction planned. The final implemented design will also require a plan for periodic monitoring on the part of the students of OSU-EWB. Chapter members, in collaboration with students and faculty from the University of El Salvador in San Salvador, anticipate making annual or bi-annual visits.

Although EWB-OSU will design and implement the final systems, community residents will be trained on how to financially and mechanically maintain the infrastructure over its entire lifespan. The development of the water-delivery system through "appropriate technology" and supporting maps, instruction manuals, and other information will play a key role in the successful transition of responsibility. The project will also depend upon gathering additional data during subsequent visits to El Salvador. Throughout this process, community members will be encouraged to participate in reviewing and verifying data from local resources and in approving the design.

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BOOK REVIEW PERSPECTIVES

Thomas Princen, *The Logic of Sufficiency*

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The publication of the Brundtland Report in 1987, followed by the Earth Summit in Río de Janeiro in 1992, brought worldwide attention to the environmental consequences of economic growth. Sustainable development quickly became one of the key visions promising changes in global and local economies. Although its undetermined definition has been widely criticized, sustainability has become the primary international political tool aimed at solving complex environmental problems. As individual countries have introduced their national sustainable development plans bringing new and stricter environmental standards to local economies, the contours of a new—much more environmentally conscious—economic paradigm are beginning to emerge.

However, the actual implementation of sustainable development plans has failed to deliver the material changes that so many scholars and environmental activists—as well as those directly exposed to environmental disasters—have been calling for. While individual countries are reducing their emissions, global levels of natural resource usage and waste emissions have never grown so fast.

Thomas Princen's *The Logic of Sufficiency* provides an in-depth analysis of why global production, distribution, and consumption systems are resistant to sustainable development plans and continue exacerbating the ecological situation. Additionally, Princen introduces a conceptually new vision of sustainable economy. *The Logic of Sufficiency* stands out from many other attempts to theorize sustainable development in that Princen moves far beyond pragmatic—economic, political, as well as social and cultural—factors to demonstrate that solving the environmental problem requires fundamental changes in the organizing logic of today's economy. Princen's main argument is that to adequately deal with growing environmental problems, we need to move from an economy built around the principles of profit maximization and efficiency to that of sufficiency.

To pursue his argument, Princen organizes his book into two parts. Part I exposes the roots of today's environmental problems and defines the concept of sufficiency as a viable alternative solution. The first two chapters in Part I problematize the implementation of efficiency and cooperation as means for solving environmental problems and introduce an alternative—ecological—rationality. Princen defines ecological rationality as a set of values resting on long-term, intergenerational resource-use goals, sustainability principles, adaptive approaches toward environmental systems, experiential knowledge of practitioners, and development of interdependencies between natural resources and social systems. Underlying these elements of ecological rationality, he argues, is the concept of sufficiency, which the subsequent chapters in Part I further contrast to the economic rationality of efficiency. Chapter Three historicizes efficiency as the key social and economic value in modern societies. Chapter Four focuses on measuring efficiency using ratios and deconstructs such measurements as value-neutral, objective systems. Chapter Five places efficiency in the context of labor history and delineates the emergence of consumer society to demonstrate that the growth of a large-scale, specialized, and limited liability corporate world is failing to deliver its promises to producers and consumers and, most importantly, regarding social and environmental well being. The second part of the book provides three specific case studies—the Pacific Lumber Company, Monhegan Lobstering, and the Toronto Island Project—where the key principles of sustainability and sufficiency were successfully implemented. These cases bridge the theory of sufficiency to the empirical world.

Among other things, Princen brings two major contributions to conceptualizing and implementing sustainability principles. First, and most prominently, the book exposes the incommensurability between an economy built around efficiency and environmental protection. He demonstrates that the governing economic principles of efficiency and profit maximization naturally displace the actual social and environmental costs of economic growth onto the public sphere. The drive toward efficiency has led to the loss of social fabric as well as to exhaustion of natural resources and often to irreversible pollution of human and natural habitats.

On the surface, Princen's criticism of efficiency is directed at contemporary economics. Yet, it has far-reaching consequences for today's environmental politics. In light of his argument, we begin to see the limits of today's sustainability politics. Indeed, can sustainability be achieved without compromising economic growth? Can we protect the environment with new and more efficient technologies or do we need more fundamental changes? Princen's answer is clear—business-as-usual is not going to work; we need to rethink the foundations of our economic activities.

In this sense, the *Logic of Sufficiency* implicitly criticizes the Brundtland Report, as well as national sustainable development plans where it is assumed that economic growth cannot—and should not—stop and where the foundations of consumer society and global systems of production and distribution are accepted as a givens. By questioning the organizing logic of contemporary economies, Princen challenges the very definition of sustainability—that sustainable development can only be achieved through the optimization of economic, social, and environmental factors. In the context of the ongoing political debates on how to better integrate science and technology into the creation of sustainable societies, Princen's book offers an important intervention into how we define and design socio-environmental systems.

Beyond theorizing sustainability around the concept of sufficiency, one of the key strengths of Princen's book is its basis in empirical case studies. As the three cases testify, the logic of sufficiency has yielded the desired socio-environmental ecologies where natural constraints are taken seriously and where socio-economic systems are designed to provide a buffer from resource exhaustion. This is important for two reasons. First, the reliance on the specific case studies bridges the vision of sustainable development with actual human practice and, by so doing, demonstrates that the implementation of sufficiency and ecological rationality is viable. For the reader, this move pushes the theory of sustainability from the purely theoretical (or political) domain to that of everyday practice. For those deeply involved in designing, implementing, living in, criticizing, or imagining sustainable socio-environmental landscapes, Princen calls for "alternative logics, ones that twist and fall, that have mystery and surprise, that do not maximize anything."

Additionally, Princen's emphasis on actual case studies suggests that the social and material infrastructures necessary for the implementation of the sufficiency principles and ecological rationality may already be in place. Even though Princen points out that instances of truly sustainable ecologies are few and far between, the case studies imply that sustainable development's future lies not in more advanced technologies and political mechanisms, but in already existing alternative practices organized around the long-term stewardship and acceptance of the limits of nature and of human control. In contrast to those who imagine that increasingly efficient resource use and new technology can achieve sustainable economies, Princen proposes a very different future where those societies that function at the current economic margins become forerunners of a new environmental regime. In this vision, "Alpine meadow grazers and Norwegian fishers and Amazonian ranchers and Filipino irrigators are not quaint throwbacks to bygone eras, but highly sensible adapters to complex environments." This observation means that some of the models and solutions for dealing with environmental problems can be found in the places near to us.

In short, through the theory of sufficiency, but most importantly, through the case studies that illustrate the principles of alternative rationality, Princen's book maps new terrain in sustainability. It not only deconstructs and historicizes the key principles of today's economic rationalities, but also questions the foundations of current environmental policies and sustainable development politics. In broader terms, *The Logic of Sufficiency* is deeply sociological and offers insights into how individuals participate in collective action, specifically in solving environmental problems. Princen demonstrates that individuals are never sovereign consumers or producers, but agents capable of changing structures. While he recognizes the significance of structures to shape one's place in a socio-environmental system, he implies that we bear individual responsibility to connect "the limits of the planet to the limits of the everyday practice." I hope that Princen's next book will flesh out how to design and steer individual practices into large-scale environmental changes. For now, I look forward to sharing this book with my students in a Green Consumerism class this semester.

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In *The Logic of Sufficiency*, Tom Princen argues for the concept of sufficiency to replace the economic rationality of efficiency, which has become the guiding principle for the management sector. However, he asserts that what is perceived to be efficient is anything but. With various examples, Princen demonstrates that economic organization based on the long-term survival of a resource being exploited is possible, and indeed desirable, and he sees this as the way out of our environmental malaise. In Chapter 1, he outlines the principle of sufficiency, then in Chapters 2 and 3 contrasts it with the history and evolution of economic efficiency as the organizing principle of the current economy. Efficiency today is interpreted in a very narrow social and economic context that in many ways has very little to do with efficiency as common sense would define it.

Princen argues on the basis of three case studies that true sustainability would mean replacing efficiency with sufficiency as the guiding concept of economics. He first discusses timber logging on the West Coast of the United States by a company that successfully put sustainable yield and selective logging as its priority and became an admirable model. His second example is lobstering in the northeastern part of the country and how a dispute over fishing-ground access led to the institutionalization of restricted access and thus a long-term view on resource availability. Princen's final study moves away from resource management to the role of the automobile and how an urban island in Toronto has made deliberate choices not to be fully co-opted into the North American model of the car society.

Researched with excruciating attention to detail, this book provides a thorough historical overview of the development of efficiency, sustainability, and sufficiency. Its strength is the theoretical and empirical treatment of sufficiency as an alternative to existing economic organization. The argument for sufficiency does not suggest a notion of sacrifice or radical lifestyle change. Rather, it questions the logic that efficiency, as defined by economies of scale and instant maximized profits without regard for the future, is the best organizing principle for the economy and society. Princen approaches this task from an ecocentric resource-use perspective and thus neatly slots into (and indeed has helped to found) a growing literature that addresses this point from a similar interdisciplinary vein. Consumer psychologists have conducted studies showing that instant gratification and indiscriminate material consumption actually lead to less rather than more happiness. A burgeoning literature on the ethics of consumption has questioned neoliberal lifestyles. Of course, various civil society movements are engaged in the same activities. Princen's work contributes to and defines this literature in a new way. It also raises questions on unaddressed issues regarding how exactly we can arrive at a society based on a logic of sufficiency.

Three areas are particularly pertinent for taking the concept of sufficiency further: public/private distinctions, the role of agency, and equity and the global dimension. In his work, Princen implies rather than articulates the interplay between public and private domains when it comes to sufficiency. While his studies of the logging industry and of lobstering are predominantly situated in the public domain, and deal with public institutions, the study of car society in Toronto's island community combines aspects of public and private agency. Sufficiency is a concept of economic organization as well as of private choice and the implications of spanning the two dimensions need to be explored further. This point ties in with questions about agency. To follow Princen's logic, we need public institutions based on sufficiency. However, we also need a more sufficient mindset in the private sphere, in the behavior of citizens and consumers that replaces consumer society's instant gratification. Achieving a change of thought in the public and private domains requires re-examining two sides of the same coin. However, seeking an ideological shift leads us back to the same well-trodden paths of civil-society engagement, education, and piecemeal change by a minority of committed citizens who will ultimately bring about new public modes. Princen stays well away from these standard recipes for averting an environmental crisis. He avoids all the clichés, but also leaves the reader hoping for a blueprint for instituting the logic of sufficiency.

The concept of sufficiency also needs international consideration through global institutions as well as through local-global linkages. Global governance discourse and environmental governance institutions generally focus on management strategies that exclude issues such as equity and reduction of resource use. Any concept of sufficiency, be it at the local or global level, could only be successful if it takes into account inequalities of wealth, power, and access to material resources, as well as such nonmaterial resources as knowledge. In a world where most rules of economic organization are made at the global level, and where the economy is based on global production and consumption patterns, the concept of sufficiency quite clearly needs a global dimension. Thus several aspects of the logic of sufficiency need to be explored further and Tom Princen's work provides an ideal starting point for considering these issues.

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Pitting oneself against the most important idea of the 20th century, even to save the 21st century from ecological collapse, creates niche appeal at best. Yet in his writings, Thomas Princen forthrightly assails the economic growth obsession and its closely coupled increasing material throughput for their role in destroying the global environment. In reviewing the works of numerous researchers in various fields with bearing on sustainable consumption, I have found none more compelling and eloquent than Princen's. His latest book, *The Logic of Sufficiency*, is a highly readable and accessible presentation, split between theory and extended case study, and unsparingly critical of the expansionist, cornucopian, consumerist political economy for eroding the ecological basis of its future sustenance. Penetrating, iconoclastic, and eloquent, the book is also as comprehensive as could be expected from a single author.

Princen's concern is the global ecological crisis: climate change, biodiversity loss, persistent toxic chemicals, dwindling freshwater, particularly the criticality of these problems, their irreversibility, long time lags, and limited predictability and control. Princen casts most of the blame on the modern political economy, especially its "shading and distancing of commerce," the tendency to export environmental threats and escape responsibility for their creation. Princen explains that "globalization, privatization, and diminishing state capacity conspire with technological innovation and market manipulation to skew the benefits and costs of economic activity, creating the illusion of environmental progress." At the heart of the problem is a central tenet of economics and engineering, hailed as a sign of progress and modernity and held up as a cure for economic, social, and even environmental ills: efficiency.

The book brilliantly, and at times acidly, deconstructs the political manipulation of efficiency ratios. Efficiency ratios are not purely technical indicators but are also political and strategic instruments. More often than not they are used to serve the interests of the commercially powerful, whose worldview is cornucopian and mechanistic, over the integrity of the global environment, which is best characterized through a complex systems perspective. Masquerading as if facilitating progress and advancing broad social agendas, efficiency ratios can be used to externalize costs over time and distance.

Trumpeting increases in automotive fuel economy, while the energy consumed by private transportation climbs steadily in the aggregate, is an example of the "individualizing" tendency of efficiency ratios. These data ignore the collective choices and the infrastructural and cultural developments that enable or constrain individual choice, for example, those that offer people scant transportation alternatives to driving. Whether a gain in an efficiency ratio translates into environmental improvement overall–for instance, whether total fossil-fuel use and carbon-dioxide emissions decline–depends foremost on personal, social, and infrastructure choices, not principally on how much technological performance has been improved per unit of energy services (e.g., gallons per mile, watts per light bulb).

Sufficiency is at the heart of the alternative rationality Princen promotes in this book in place of the economistic and legalistic rationalities that champion efficiency. In former times, discussing sufficiency might have been considered as banal as lauding the age-old virtue of moderation; today, it is necessary to explicate sufficiency since excess has been so deeply systematized in economic theory and society that it has become the water in which we all swim. Restraint, a key component of sufficiency, functions when biophysical signals register in human social systems, establishing a negative feedback loop to ensure the ecological integrity of the resource base. To restore restraint and sufficiency, Princen argues, companies and social institutions must be reordered so that resource managers can receive and act on these signals. The book's in-depth case studies show sufficiency in action through people's apprehension in intuitive, experiential ways without top-down coercion, technocratic knowledge, strong environmental convictions, or loss of the profit motive.

As a normative class of prescriptive principles, sufficiency stands in strong contrast to cooperation and efficiency. Similarly, the logic of sufficiency is necessary to *counter* the logic of capital(ism), and not–as in popular sociological theory–to be applied alongside it. The two logics are fundamentally opposed in their *Weltanschauung* concerning material use. Princen also criticizes the standard environmental protection approach and, implicitly, standard sustainability formulations, as inadequate or misguided. Sustainability is often described as a balanced triad of environmental, social, and economic interests. However, although it is apparent by now that economics as normally practiced ("sustainable growth") is frequently antithetical to long-term ecological integrity, few practitioners admit it openly. To his credit, Princen points out this elephant in the bedroom of conventional moderate sustainability advocates.

The Logic of Sufficiency departs radically from the mainstream in both its message and its target audience. Princen admits he is preaching to the choir in this book and holds no hope of converting the non-ecological, rationalist majority to his views. Most of the public, as well as policy makers and media-opinion setters, he suggests, will only be convinced by mounting inconsistencies as they are forced to reckon with ecological constraints, or society will have to wait for them to die off. But this may prove too late. If things are as bad as Princen fears, why is he not more concerned about running out of time before the majority sees the light?

In effect, then, the book is something like intellectual and moral support for the faithful to keep them from losing themselves and their hope before the neoliberal onslaught. One wonders if such a thorough deconstruction of efficiency and associated shibboleths is necessary for his intended audience to remove all doubts and make them true believers. Princen says the promise of sufficiency is hope. Herman Daly, one of the founders of ecological economics, has tried to deliver a similar message in academia and at the World Bank without having made an appreciable dent in the contemporary obsession with (throughput) growth. I suggest we need a parallel approach with a somewhat more mainstream appeal that is still faithful to this message and mindful of the late hour. Somehow, and better sooner rather than later, we must begin to mainstream the ultimate economic heresy.

To this end, it may help to anticipate the main camps of resistance to Princen's arguments in the book. As noted, the proponents of the growth-centered neoliberal order will dismiss the book as environmentalist radicalism, rabid antiglobalization, or a recipe for economic depression–assuming they ever hear of it.

- Fellow social scientists, even environmental ones, may find it academically questionable or intellectually inauthentic to be so overtly normative and prescriptive.
- Policy makers will struggle with Princen's contention that sufficiency operates with a comfortable buffer from the maximum. What this means in practice is to be established experientially from years of close contact with the resource in question (e.g., a fishery or a forest), and not experimentally or exactly through modeling. The suggestion that sufficiency is not rigorously quantifiable will rile many policy makers, who will say if it is not quantifiable, it is not amenable to their manipulation and control, and therefore none of their concern.
- Environmental economists, engineers, and other advocates of ecoefficiency will bring technological and economic arguments against Princen's relentless criticism of efficiency as one of the causes of, not a solution to, the ecological predicament. They will be especially critical of his refusal to be content with lamenting efficiency's extension beyond the factory floor to social and cultural realms. During the transition to a renewable energy system, and while existing housing and transportation infrastructure is still being replaced, they will argue, improvements in technological efficiencies are vital to our ability to extend the nonrenewable resource base and to reduce emissions. In the name of environmental protection—or more to the point sustainability—can one champion increases in efficiencies in the technological realm as long as they are not extended to the wider society? It is arguable whether most technological efficiency increases are self-defeating by precipitating throughput increases. Princen also suggests that at the same time that efficiencies are improved, consumption cannot be successfully held down via conventional policy instruments like taxes, but others dispute that as well.

The Logic of Sufficiency belongs to the body of visionary sustainability literature. It describes how and why the current political economy is undermining the environment and provides a clear vision of how it should be arranged under conditions of sufficiency, with rigorous elaboration of principles, conditions, and even enabling institutional conditions. The advocates of alternative reasoning and alternative choices need more than an ideal or a utopian fantasy, they need a realistic option, he says. But Princen's work *is* utopian, if brilliantly so; he uses real-world examples of sufficiency in action, but while they may not be on the fringe, they are very small scale. The tiny holdouts against completely open-access automobile and airplane mobility on Toronto Island, for example, are not nearly enough to constitute a critical mass for social change. Princen derives many sufficiency principles from those who interact directly with natural resources–fishermen, loggers, farmers–but are these ecological rationalities scalable to the global economy? Princen does not offer much about how to get from here to there on a global, or even a national, scale. The mechanics of a smooth transition are important and likely to be much more problematic than Princen hopes when he writes, with reference to the American factory farm meat-production system (an apotheosis of efficiency), "it is really quite simple. And thoughtful people know society will get there one way or another." Some ways will prove much uglier than others.

All of Princen's longer case studies are in North America. How extendable are the lessons he draws from them to the rest of the world? Despite globalization based on the Western model, legal and cultural idiosyncrasies in other countries may limit their generalizability. And most troublesome, what about the growing parts of the world that are immune to the logic of sufficiency, and to the logic of capitalism for that matter, whether because of corruption, dictatorship, thuggery, or militant fundamentalist ideologies?

Princen devotes relatively little space to individual human agency. With the accelerating loss of the global "sustainable middle" class, there are strong socioeconomic and strategic reasons why people, even if they agree with Princen's sufficiency principles, will not embrace them as long as they are marginal or transitional. In the United States, to avoid slipping into the class confined to polluted, deteriorating, crime-ridden urban neighborhoods with execrable schools and public transportation, many are forced to "buy into" the global political economy. And even those who subscribe to sufficiency in their personal lives will likely eschew embracing sufficiency's implications at the professional or political level.

In a smaller illustration, Princen cites dairy farming in the Alpine regions of Switzerland, my adoptive country, as an example of a sustainable practice in a region where farmers continue a centuries-old lifestyle. He notes that Alpine farming is not the basis of the Swiss economy, and in fact these communities are now only economically viable with enormous subsidies from the central government. This is money raised largely via an economy of international banking and finance that feeds on and fuels the unsustainable global economy.

At the individual, communal, and national levels, problematic interconnections complicate the search for an ecological ethic of behavior that still enables one to survive. On one hand, what guidance would Princen offer in conducting oneself to avoid complicity in an amoral political economy whose operation is undermining the biophysical basis of future life and civilizations?

On the other hand, we may rest easier not probing too deeply. Princen means to lend moral support to the faithful as they hew to a different, lonely path, but shedding too much light can lead to guilt, moral paralysis, environmental fatigue, or fatalism. As Solomon noted in the Book of Ecclesiastes, "For in much wisdom is much vexation; And he that increases knowledge increases sorrow."

Rejoinder from the author

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First a word of gratitude to Editor Maurie Cohen for organizing these book reviews on *The Logic of Sufficiency*. And another word to the reviewers for their careful reads and thoughtful comments. I hope my reply is worthy of all four people's efforts.

Second, it is, of course, gratifying to have one's work so reviewed and, as it turns out, on the whole, reviewed so positively. In the interest of pushing the conversation further (the conversation on the conditions for sustainability, say), I will refrain from noting points of agreement and instead focus on those of disagreement, or at least on those that warrant elaboration and clarification, and those that call for next steps.

Diana Mincyte usefully frames the contribution of *The Logic of Sufficiency* as a way "to see the limits of today's sustainability politics." Gabriela Kütting takes sufficiency as that which "questions the logic that efficiency…is the best organizing principle for the economy and society." And David Goldblatt interprets it as a "counter [to the] logic of capital(ism)." I find these to be useful frames, yet more negative than I had intended. Environmental studies and, for that matter, academe, is almost cursed by its focus on the critique, on the analysis and deconstruction of existing theory and practice, all as if the alternative just follows. I prefer to think of sufficiency (and like concepts) as a positive step toward the alternative. Of course, the risk, as I have witnessed already in some not-so-complimentary reviews, is to be slammed for being "normative" (which to me is no slam at all; see below) or ideological or naïve or "utopian." So here I wish to make three points, calling for normative theorizing, for more concept development, and for care in getting the applications right.

The first point is theoretical yet starts with the empirical (where I believe all theory should start). The case studies are indeed all in North America. In part this is because of geographical and cultural proximity, and in part it is because it just so happens that North America is the source of much of the world's global dynamic of endless growth, consumerism, the depreciation of work, the rhetorical use of efficiency, and so on. I cannot wait to see related empirical work in other cultural settings. Then, and maybe only then, we might be able to formulate a "theory of sustainability."

Kütting describes the book as a "thorough historical overview of the development of efficiency, sustainability, and sufficiency." I accept that description for efficiency but this work, as incomplete and preliminary as it is (in my mind), is really an exercise in normative theorizing. And that theorizing is simultaneously broad (with respect to the large societal goal of sustainability) and narrow (with respect to principles—just one, sufficiency). I raise this because I think all of us, academics and practitioners, who hope to make a contribution to reversing the trends in environmental degradation and getting society on a sustainable path have to accept that our work is not primarily a descriptive, explanatory, or predictive enterprise; it is a normative one, just as are all those academic enterprises that claim to be strictly "scientific" or "historical" or "realist" or "positivist."

That said, I am somewhat surprised that none of the reviewers found fault with the avowedly normative stance of the book. Maybe this is only an issue for the positivists, those remaining hard-core scientists and wannabe scientists who still believe values do not infuse their work. As one who encounters such believers almost daily, this is an issue, and not just a methodological or theoretical issue. The positivists do believe they are doing good by objectively and neutrally collecting data, analyzing them, and dispersing the results to the public and policymakers. They can conduct five-year, million-dollar studies and wholeheartedly believe that doing so will make the difference, especially if we can keep the "politics" out of it. To take this position is to implicitly act as if the current political economy is the wealth-generator we have and the wealth-generator we must work with, as if the current political economy is not fundamentally flawed, as if a bit of tweaking, a little fine tuning of this otherwise perfect machine, is all that is needed.

The rest of us can lament the narrowness of this belief system, even its naiveté; we can deconstruct the assumptions and demonstrate the implicit values that inform the science. We can show there is a "politics" in everything, in concepts like efficiency and, yes, sufficiency, and in science itself. But somehow we have to do better, notwithstanding Thomas Kuhn's observation that many of those wedded to their paradigm will just have to die off. I do not have the answer, but I suspect it is going to start with a demonstration of the narrowness *on their own terms*. For example, the Stern Report on climate change that came out of Britain last year was supposed to be an economic assessment of, in its words, "the greatest market failure the world has ever seen." Yet many of its key recommendations were about cultural change—education, public awareness, international cooperation, partnership. Moreover, there was no critical assessment of, for instance, the use of discount rates or the structure of capital markets, nothing that would connect such instruments and institutions to the very problem at hand—namely, excess throughput of material and energy resulting in the destabilization of a complex system with limited predictability, a system called "the climate." This is the critical task as I see it. And the necessary complement to the critical is the normative, that is, normative theorizing and, my second point, concept development.

Every major societal goal (from democracy to peace to economic growth) is subject to distortion and dilution by the "politics." We saw that with efficiency. The challenge for those of us who see sustainability as a major goal of our time, if not *the* major goal, is to continually debate and refine that goal, just as proponents of democracy and peace must do, and just as proponents of endless, harmless growth have so successfully done. Part of our project is to develop a language (literally and conceptually) to fit the distinctiveness of the goal. Hence, sufficiency—and polluter pays and precaution and zero discharge and reverse onus. But we need more, lots more so that we can analyze and apply them and, after sifting and winnowing, select the good ones, those that really do, as Mincyte says, create "fundamental changes in the organizing logic of today's economy."

I emphasize this need to proliferate new concepts (including variations on old ones) so as to guard against the propensity we all seem to have to seize upon the latest concept as "the next big thing" and then subsume all sundry objectives under that new thing (think peace, freedom, sustainability). I have actually experienced a bit of that with sufficiency where some readers have attempted to stretch the concept to, in effect, become the next sustainability, or sustainable development, or conservation. The more I think about this concept-stretching issue, the more committed I become (theoretically and otherwise) to developing *many* principles, not *the* principle. And then the real task becomes analogous to nature's practice of producing more individuals than will survive, more brain cells than are needed, and allowing selective pressures (e.g., political processes, human need, self-organization) to identify the successful ones.

So, for example, Kütting interprets the book's theme as replacing efficiency with sufficiency in management and economics. I prefer to see the theme as *subordinating* efficiency to sufficiency and other ecologically informed principles. This distinction is important because it points to the ongoing need to construct a *hierarchy* of social organizing principles for sustainability. I do believe that a well-specified efficiency principle will be in that hierarchy, only *below* principles like ecological capping, zero waste, buffering, problem absorption, precaution, and polluter pays.

The third point regards "next steps" and "how to get from here to there" which, in different ways, all reviewers call for. I must say, upon finishing this work, that is exactly what I had intended. Before I knew it, though, I was working on a "neo-prudential order," the conditions for anticipation and prevention, for long-term decision making, for a coherent theory of sustainability. Deciding how far to go into the applications realm is an issue all of us academics must grapple with. I have come to the conclusion, cop-out though it may be, that my niche is social theorizing.

Others are far better at making the translations to practice. As partial confirmation of this position, I have been pleased to learn that professionals in electric power utilities, in the energy-conservation field (even the energy *efficiency* field!), in environmental protection agencies (e.g., the United States Environmental Protection Agency), in nongovernmental organizations (e.g., environmental health, globalization, consumerism), and foundations, not to mention academics from sociology to religious studies to engineering to, of course, environmental studies have indicated they are using *The Logic of Sufficiency*. I prefer to see my work as informing their work, as being one of many tools they can use. And I see the most useful "next steps" (in addition to working with some of these practitioners, which I am doing) as going beyond sufficiency, not only proliferating concepts and principles, but exploring questions of transition, as Goldblatt rightly emphasizes.

The how-to-get-there question is indeed important and, despite my assertion, not "simple" (certainly not in the sense of "easy"), and, yes, much will be ugly. Personally, I am reluctant to jump straight to projects and regulations, if for no other reason than that such ideas tend to be recycled variants on the same theme—more office recycling, more fuel-efficient cars. A far better task, especially for academics, is to parse out theories and histories of transition, formal and informal, explicit and implicit. The prevailing ones, it seems to me, are incremental change, technological innovation, market correction, and education. Another is organic reinvention, the bottom-up reassertion of control of basic natural resources such as food and water. I trust there is a relevant literature on transitions that sorts this all out. If not, here is an area ripe for research.

Kütting calls for better bridging of the public and the private realms. I agree, but I wonder how distinct really are the two realms. If the history and rhetoric of efficiency is any guide, they are not, no matter how useful analytically the distinction might be. And for the objective of transitioning to sustainable practices, it might be best to avoid the distinction altogether so as to find principles that are generally applicable.

On the other hand, Kütting is absolutely right that an extended sufficiency should include "the role of agency, and equity and the global dimension." Regarding equity and the global, I am inclined toward developing new principles rather than, as noted, risking the all-too-familiar pattern of stretching a concept to fit all agendas. Again, I find it more useful to conceive of a nested set of principles each of which addresses distinct concerns—e.g., ecological integrity, human security, environmental justice—and to guard against concept stretching.

Put differently, even if sufficiency makes perfectly good sense, even if it is logical, economically, socially, and ecologically logical, it is only one social organizing principle of sustainability, indeed one candidate for a principle of sustainability. So many times I have felt stumped in my professional and personal life bumping up against the other principles—efficiency, growth, cooperation. I am as much a product of the dominant unecological principles as anyone (disclosure: I taught microeconomics in a well-regarded institution for a number of years—and zealously so!). All of us who know that the world needs an alternative framework must offer up tools to counter the hegemonic framework. We have a lot of work to do developing new principles, new stories, new ways of understanding the good life and justice and democracy.

Finally, Goldblatt makes a plea for urgency, arguing that providing the "intellectual and moral support for the faithful" is useful but what is really needed is to "mainstream the ultimate economic heresy," namely, to challenge economic growth. I share that sense of urgency and need for mainstreaming but the question, as always, is how. *The Logic of Sufficiency* does no more than offer one tool, one concept (with some subconcepts like restraint and respite), one that is hopefully well grounded in practice and well constructed in theory. And, yes, for now it cannot pretend to convert the very people who have structured their lives around the current order and benefited so handsomely from it. But that order is changing, rapidly it seems to me. The "faithful" are no longer us "good enviros" but a wide swath of people, across the ideological and socio-economic spectrums, people who realize the system is broken, fundamentally broken. The more bankrupt it appears to people, the more they will cast about for new ideas and models and stories. This is where notions like sufficiency come in. No one such idea is, or should be, "the answer." They all should be tested and subjected to various forms of selective criteria (e.g., is it really "ecological" and amenable to just outcomes?). And they should be intelligible to specialist and lay alike. Yes, there will be "camps of resistance." But they do not trouble me: a couple more "Katrinas", a foot or two of sea-level rise, a race to find "new sources" of freshwater, and these skeptics are suddenly irrelevant. Let us prepare for that day!