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# Illustrating integrated sustainability and resilience based assessments: a small-scale biodiesel project in Barbados

**Kyrke Gaudreau and Robert B Gibson**

Assessments today need to help reverse trends towards deeper unsustainability and address the unavoidable interconnections, feedbacks and uncertainties that typify complex socio-ecological systems at all scales. To illustrate one promising approach, this paper describes a modest effort to integrate understandings from Gibson et al's approach to sustainability assessment with the Resilience Alliance's applications of complex systems thinking into a suite of systems and sustainability based criteria. The integrated sustainability–resilience criteria were used to assess an existing small-scale biodiesel operation on Barbados that involves waste management, public health, transportation, energy security and community involvement considerations. The assessment revealed that the main benefit of this biodiesel project is in social learning rather than enhancing energy security and waste management, and the best ways of enhancing the project lie in larger scale policy initiatives. The findings suggest that the use of a sustainability–resilience approach can contribute insights unlikely to emerge from more narrowly focused assessments.

Keywords: sustainability assessment, resilience, biodiesel, systems analysis, multi-criteria assessment

TWO OF THE MOST SIGNIFICANT challenges facing impact assessment in the 21st century are the needs to reverse trends towards deeper aunsustainability and to address the unavoidable interconnections, feedbacks and uncertainties that typify complex socio-ecological systems at all scales (Holling *et al* 2002). These challenges are closely connected. Many of our failures to behave in a sustainable manner are a product of fragmented, narrow thinking and hubris.

An evident implication for assessment work is that the selection, design and implementation of important undertakings — policies, plans and programmes as well as projects, large and small — ought to be guided by integrated attention to sustainability requirements and complex systems realities. Conceptual work in both the sustainability and complex systems literature has recognized the desirability of such integration (Francis, 2006; Kay, 2008; Bunch and Ramirez, 2009), and many practical strategic and project-level undertakings have at least implicitly explored means of integrating systems and sustainability considerations (Rotmans *et al*, 2000a, b; Buchholz *et al*, 2007; Partidário *et al*, 2009). So far, however, these efforts still represent the initial explorations of a wide range of rich possibilities.

This paper attempts to illustrate what can emerge from a modest effort to integrate and apply understandings from the two fields in the fassessment of a particular undertaking. The work centres on the development and application of a comprehensive set of evaluation criteria that combine generic systems and sustainability considerations with recognition to the

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particular concerns arising from the case and context of a small, existing biodiesel operation on the island of Barbados.

The case application here has two core foundations. The first is a sustainability assessment approach built by Gibson *et al* (2005), which synthesizes insights from the literature on requirements for progress towards sustainability and is essentially defined by its focus on how the interrelations of these requirements can be addressed in ways that deliver multiple, mutually reinforcing and lasting gains. The second is the application of insights from the study of complex socio-ecological systems, relying chiefly on the systems understanding that underpins the ecosystem approach (Kay *et al*, 1999; Waltner-Toews *et al*, 2008) and on the Resilience Alliance's identification of the properties of a resilient world (Walker and Salt, 2006; The Resilience Alliance, 2007a, b). Both point to desired system traits (e.g. resilience, flexibility, modularity and reversibility) that can be maintained and enhanced. These two foundations overlap and each has been applied in some forms of assessment (Gibson, 2006; Walker and Salt, 2006; Gibson *et al*, 2008; Waltner-Toews *et al*, 2008), but the two have not previously been integrated and applied in any published work so far as we know.

Because the resulting approach to assessment is centred on sustainability and resilience objectives, it is considerably more ambitious than assessment work that aims only to reduce biophysical damage. The integrated sustainability–resilience approach is, however, not a long stretch from comprehensive and ambitious forms of environmental impact assessment in which 'environment' is defined to include social, economic, cultural and biophysical components and their interactions; the objective is durable betterment rather than mere mitigation of significant adverse effects; and the assessment agenda covers implementation as well as selection, design and approval of the relevant undertakings.

To illustrate the application of an integrated sustainability–resilience approach we have used it to assess a small, apparently 'green' initiative that involves collecting used cooking oil from restaurants and other food-related businesses and converting the oil into biodiesel, which may be used as a transport fuel. In addition to reducing dependency on imported conventional diesel, the initiative promises to serve waste management, public health, transportation and community involvement objectives. Whether the biodiesel operation does deliver benefits in these and other areas, and whether it has other strengths and limitations as a potential contributor to sustainability and resilience, are the main immediate questions underlying the application here. For our purposes, the Barbadian biodiesel case has the advantages of being potentially attractive from a sustainability and resilience perspective, broadly similar to countless other initiatives, and small enough to illustrate how a quite modest sustainability and resilience based review can serve common project evaluation purposes.

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*Post-hoc* application to an ongoing undertaking rather than an anticipated one departs from the usual emphasis on assessment of proposed undertakings, but benefits from more evidence about actual effects. The lessons from the case discussed here should be nonetheless relevant for potential application to the development and review of new proposals.

## Methodology

The basic methodology illustrated here centres on combining established sets of generic sustainability assessment and resilience analysis criteria in the specification of an evaluation framework for the particular case and context of our illustrative small biodiesel operation in Barbados. The specified criteria were used to identify the key strengths and limitations of the biodiesel project, to assist consideration of their implications as a package, and to help identify ways by which the operation could make more consistently positive contributions to sustainability and resilience.

### *Sustainability assessment criteria*

The generic sustainability assessment criteria set out in Table 1 (from Gibson *et al*, 2005) were developed for a wide range of applications in broadly defined environmental assessments and planning. They are meant to cover the full set of key requirements for progress towards sustainability, with emphasis on the interrelations among these requirements and attention to the potential for an upward spiral of positive feedbacks for mutually reinforcing gains. To encourage integrated thinking, the generic categories have been defined to avoid the usual reductionist triple bottom line pillars of sustainability (Gibson *et al*, 2005).

These generic sustainability assessment criteria provide a common base for assessment anywhere and on any undertaking, and apply to examination of options and results at all stages of an assessment process from the initial delineation of purposes, through comparative evaluation of alternatives and potential approval options, to implementation and

**Table 1. The generic sustainability assessment criteria**

| |
|---|
| **Socio-ecological system integrity** — Build human–ecological relations to establish and maintain the long-term integrity of socio-biophysical systems and protect the irreplaceable life support functions upon which human as well as ecological well-being depends. |
| **Livelihood sufficiency and opportunity** — Ensure that everyone and every community has enough for a decent life and that everyone has opportunities to seek improvements in ways that do not compromise future generations' possibilities for sufficiency and opportunity. |
| **Intragenerational equity** — Ensure that sufficiency and effective choices for all are pursued in ways that reduce dangerous gaps in sufficiency and opportunity (and health, security, social recognition, political influence, etc.) between the rich and the poor. |
| **Intergenerational equity** — Favour present options and actions that are most likely to preserve or enhance the opportunities and capabilities of future generations to live sustainably. |
| **Resource maintenance and efficiency** — Provide a larger base for ensuring sustainable livelihoods for all while reducing threats to the long-term integrity of socio-ecological systems by reducing extractive damage, avoiding waste and cutting overall material and energy use per unit of benefit. |
| **Socio-ecological civility and democratic governance** — Build the capacity, motivation and habitual inclination of individuals, communities and other collective decision-making bodies to apply sustainability requirements through more open and better informed deliberations, greater attention to fostering reciprocal awareness and collective responsibility, and more integrated use of administrative, market, customary and personal decision-making practices. |
| **Precaution and adaptation** — Respect uncertainty, avoid even poorly understood risks of serious or irreversible damage to the foundations for sustainability, plan to learn, design for surprise, and manage for adaptation. |
| **Immediate and long-term integration** — Apply all principles of sustainability at once, seeking mutually supportive benefits and multiple gains. |

*Source:* Gibson *et al* (2005, chapter 5)

eventual closure or renewal. In all applications, however, specification for case and context is needed. Approaches to such specification have been documented, particularly for a major project review (Gibson, 2006) and for evaluation of a proposed provincial-scale, electricity sector systems plan (Gibson *et al*, 2008), but have not explicitly incorporated attention to resilience criteria.

### *Resilience criteria*

Resilience approaches to social–ecological systems issues commonly faced in environmental assessment emerged largely from the domains of ecological modelling and resource management. While not as comprehensive as the sustainability assessment agenda represented by the criteria above, resilience thinking is useful in elucidating system dynamics within and among various scales (Walker *et al*, 2004; Walker and Salt, 2006). Resilience analysis is still being developed as a methodology, with preliminary forms described in several works including the Resilience Alliance workbooks (The Resilience Alliance, 2007a, b). Because of their respect for system complexity and uncertainty, advocates of resilience thinking and associated analyses are hesitant to embrace prescriptive approaches that might encourage overconfidence in prediction and management. With this caveat, Walker and Salt (2006) identify the nine properties of a resilient world that are presented in the form of criteria in Table 2.

These nine criteria are narrower in scope than the sustainability criteria, in part because they do not attempt to identify the desirable qualities of socio-ecological systems beyond the capacity to adapt and persist. The resilience criteria do, however, complement the sustainability based assessment criteria in several important ways. They clarify the qualities needed for socio-ecological integrity and suggest means of acting on requirements for precaution and adaptation. Moreover, they temper the sustainability criterion for enhanced resource and energy efficiencies by pointing to the need for sufficient system redundancy and for safety cushions between exploitation levels and potential system thresholds. At least for the purposes of the present case study, the resilience criteria can be integrated with the generic sustainability assessment criteria most effectively by direct insertion as clarifications and adjustments of the sustainability assessment criteria and by giving particular attention to the resilience qualities in the elaboration of case and context specific criteria.

### *Integrating and specifying sustainability and resilience criteria*

Both the sustainability and resilience criteria have been conceived for broad application to evaluations of situations, options and undertakings of various kinds, scales and locations. In every application, however, the particulars of case and context are crucial. Different contexts feature different trajectories, capacities, vulnerabilities, possibilities and preferences; different cases raise different options and face different influences, barriers and openings. Neglect of these is likely to be fatal to prospects for success. Development of evaluation criteria for an individual case and context therefore requires integration of the generic criteria with attention to the key case and context factors — especially those that define aspirations and limitations.

Identifying all the potentially relevant case and context specific factors, and their interrelations, for any case is probably impossible. While there can be no end of debate on what is needed for an adequate understanding, it is evident that highly ambitious research and analysis is not always necessary. For

**Table 2. Criteria for resilient societies**

| |
|---|
| **Diversity** — Promote and sustain diversity in all forms (biological, landscape, cultural, social and economic) as a major source of future options and system capacity to respond to change and disturbance. |
| **Ecological variability** — Embrace and work with ecological variability rather than attempting to control it (e.g. to maximize returns). |
| **Modularity** — Favour largely self-reliant systems (modules) to avoid over-connectedness and associated relations of dependence, which become vulnerable to shocks. |
| **Acknowledge slow variables** — Focus on slow controlling variables that configure social/ecological systems and are associated with thresholds. |
| **Tight feedbacks** — Maintain or strengthen feedbacks that are tight and strong enough to allow detection of thresholds before they are crossed (versus slow or delayed feedbacks with weak signals). |
| **Social capital** — Promote trust, well-developed social networks, and responsive leadership, all of which serve adaptability. |
| **Innovation** — Emphasize learning, experimentation, locally developed rules, and capacity and willingness to shift away from thresholds to undesirable futures or over thresholds to more desirable futures. |
| **Overlap in governance** — Foster redundancy of institutions, and a mix of governance players and relations and tools (e.g. common and private properties with overlapping access rights) to increase response diversity and flexibility. |
| **Ecosystem services** — Recognize all ecosystem services, including those currently unpriced (e.g. pollination, water regime maintenance, climate reliability and nutrient cycling). |

*Source:* Adapted from Walker and Salt (2006, chapter 6)

cases of limited potential impact and controversy, where time and resources are more constrained, and where the key factors are already quite clearly evident due to earlier expert studies and public deliberations, reliable conclusions can be drawn from a more modest combination of research methods including review of existing literature, key informant interviews and participant observation. In all situations, however, it is important to spend sufficient time immersed in the case and context to gain an adequate understanding of the realities behind the standard accounts and common assumptions.

## Sample application: small-scale biodiesel in Barbados

To illustrate application of a sustainability–resilience framework, we assessed an existing small-scale biodiesel plant in Barbados. As noted above, the first step involved constructing a framework for assessment by integrating and specifying the generic sustainability and resilience criteria for the particular case and context (presented in Table 4, below). For the purposes of this exercise, the research into the particulars of the biodiesel operation and the relevant aspects of the Barbadian context drew on three different sources of evidence: documentary evidence on the biodiesel systems and related aspects of the Barbadian socio-economic and ecological systems, participant observation working with the biodiesel operation over a three-month period in 2008, and informal interviews with stakeholders directly involved in the biodiesel system. To build a better understanding of the small-scale biodiesel operation and options, a system description was also undertaken.[1]

Even for an illustrative review of a small and uncontroversial undertaking, details are important, especially where they involve the range of potentially feasible alternatives to current project design and operation, and the interactions among contextual factors that influence project viability and effects. A full reporting of those details is not possible here; however, the following summary should provide an indication of the key considerations.

### *The context*

Barbados is a relatively prosperous Caribbean island. Nonetheless, like many other small island nations, it faces significant sustainability and resilience challenges. Some of these are rooted in its reliance on and vulnerability to outside forces (from global economic shifts and oil price changes, to changes in tourist behaviour and international steps to discourage tax dodging) over which it has little influence. Also, like many other jurisdictions, Barbados suffers from disparities in opportunity and participates in productive and consumptive activities that cannot be maintained in the long run. These considerations suggest needs for further economic diversification, enhancement of self-reliance, conversion to renewable energy sources, and development of more broadly distributed livelihood opportunities (UN, 1994, 2007; SIDS, 2003).

Means of acting on these needs are constrained by the island's limited resources. A large percentage of food is imported (WRI, 2006), especially to meet tourist demands. Barbados is also one of the 15 most water-scarce countries in the world (Sealy, 2006), is only 5% forested (Mongabay, 2007), and is quickly running out of landfill capacity (Barbados, 2004). Finally, Barbados imports approximately 90% of its oil, and almost all of its other fossil fuels (EIA, 2009), in part to serve electricity production, all of which is fossil fuel based, with the primary fuels being diesel, fuel oil and natural gas (BL&P, 2009). Recent Barbados energy policy aims to reduce dependence on imported fossil fuels by replacing the imports with indigenous renewable energy production (Sealy, 2006), such as the recently proposed ethanol fuel cane project (Lutter, 2007).

### The case

The case study biodiesel system is a small-scale biodiesel plant in the centre of the island. At the time of the research, the plant employed three workers (two men and one woman). The used cooking oil necessary for biodiesel production was collected by pickup truck from a wide range of suppliers (a restaurant chain, individual restaurants, road-side stands and a local high school), with support from a United Nations Development Programme grant. As well, many individuals voluntarily donated their stored used cooking oil after hearing about the biodiesel operation through the news or by word of mouth.

Biodiesel production was based on first-generation thermo-chemical technology that produces biodiesel and glycerin from methanol, vegetable oil and sodium hydroxide using a process known as trans-esterification. This first-generation system is common for small-scale projects (Kemp, 2006; Phalakornkule *et al*, 2009).

Small-scale biodiesel production is characterized by many different possible variations in input and processing. The available variations add to system resilience by providing a diversity of input and organizational alternatives that can be adopted if problems emerge in the use of the current components, although conversion from one configuration to another is not necessarily easy. Some possible variations are provided in Table 3.

While the main output is biodiesel, the process also produces glycerin (0.2 L glycerin/L biodiesel) and washwater (3 L washwater/L biodiesel) (Callender, 2008, personal communication). Both the glycerin and the washwater are toxic — contaminated with sodium hydroxide, methanol and raw biodiesel (Kemp, 2006).

One disadvantage of the small-scale production system is the relative difficulty of maintaining quality control, as formal quality control (e.g. ASME standards) is often prohibitively expensive for small-scale operations (Kemp, 2006, chapter 8). Many small-scale producers rely instead on experience and simple non-standardized tests of fuel quality (Kemp, 2006; Callender, 2008, personal communication). This can be insufficient and, in the extreme case of poor quality biodiesel, engine damage may result.

A second diseconomy of scale involves input costs. For example, methanol purchased in small units can account for a large percentage of the production cost (Callender, 2009, personal communication). The resulting high input costs result in a low profit margin which, when coupled with the small volumes of production, undermines financial feasibility.

### The case specific sustainability and resilience criteria

The specification of the combined generic sustainability and resilience criteria for the particular case and context was initiated as a group exercise that included the researchers, interns working at the biodiesel plant and key stakeholders involved in the biodiesel operation. The work relied on data from the documentary evidence, participant observation and informal interviews, and was informed by development of a systems description depicting linkages within the operation and between the operation and the larger environment. Moreover, an iterative process was used, so that development of case specific criteria (presented in Table 4) both guided and was influenced by the preparation and initial test uses of the sustainability–resilience assessment table (presented in Table 5).

### Application of the criteria

An initial version of the case specific criteria in Table 4 was adopted as the basis for a first draft of the sustainability–resilience assessment that centred on developing and filling out a sustainability–resilience assessment table, The final version of that table is reproduced as Table 5, which sets out the most significant particular considerations related to the final Table 4 criteria. While the result appears as a linear development from the criteria table to the assessment table, in practice the two tables were prepared jointly, through several iterations of adjustments of each table, involving decisions on what to include where, and with what emphasis and specificity.

Throughout the iterations, care was taken to ensure all the generic criteria in Tables 1 and 2 were addressed in the case specific criteria in Table 4 and all of these specific criteria were addressed in the

**Table 3. Production alternatives**

| Location | Barbados case | Variations |
|---|---|---|
| Input | Methanol | Ethanol and other alcohols |
| | Waste cooking oil | Other vegetable oils, as well as fats, oils and greases |
| | Sodium hydroxide | Potassium hydroxide, sulfuric acid |
| | Water for washing | Waterless washing, e.g. using Magnesol (Bryan, 2005) |
| | Electrical heat | Passive solar or natural gas heating |
| | Electrical mixing | Pedal-powered mixing (Vaidyanathan and Sankaranarayanan, 2007) |
| Operation | Batch processing | Continuous processing |
| | Single operator | Multiple operators, each capable of performing all or a subset of the tasks |

**Table 4. Case specific sustainability criteria for the Barbados biodiesel operation**

**Socio-ecological system integrity and resilience**
How does the operation affect:
- the capacity of the local ecosystem to deliver valued ecosystem services reliably into the future (e.g. effects on water and air quality, and wildlife habitat)?
- the capacity of national and global ecosystems and socio-ecosystems to deliver valued services reliably into the future (e.g. effects on regional pollution levels, energy sources and transport systems)?
- the resilience of local and national socio-ecosystems (including economic options, transportation, food and health systems, water and waste management)?
- longer term availability of non-renewable and renewable resources?

**Livelihood sufficiency and opportunity**
How does the operation affect:
- opportunities for lasting employment?
- human health (including exposure to toxic substances and sanitation issues)?
- the availability of resources for others?
- learning and associated capacity building, including the indirect effects on education and training by other bodies?
- potential for further investment and scale enlargement?

**Intragenerational equity**
How does the operation affect:
- the unequal distribution of wealth, access to resources, and influence on the island?
- the equality of access to health, valued employment, respected knowledge and community security?
- gender equality on the island?
- the distribution of wealth, influence and access to resources between advantaged and disadvantaged nations (including effects on revenue flows, dependency effects, etc.)?
- the material and energy intensity of consumer and other satisfactions for the wealthy?
- the well-being of non-human species (including effects on habitat, quality of ecosystem services and vulnerability to stresses)?

**Intergenerational equity**
How does the operation affect:
- potential costs and benefits for future generations?
- transition towards a future energy supply?
- legacy costs (e.g. storage of long-term wastes)?

**Resource maintenance and efficiency**
How does the operation affect:
- the severity of damage from resource extraction (over full life cycle, including induced and cumulative effects) as compared to existing practices and to alternatives?
- the net use of energy, energy quality matching and the nature of energy sources (including any bridging to renewable and low impact sources)?
- the net use of water (including effects on availability of water for ecosystem functions as well as human needs)?
- the net use of other materials and resources, and the potential hazardousness of direct and embodied pollution and other wastes?
- the transition from non-renewable high impact energy and material sources to renewable and low impact sources?
- the potential for rebound effects (e.g. savings from biodiesel efficiencies facilitating expansion of demands and adverse effects elsewhere)?
- the potential for efficiencies that reduce desirable diversity, local suitability and redundancy?

**Social–ecological civility and democratic governance**
How does the operation affect:
- the social awareness of citizens (including through involvement in framing problems and solutions, opportunities to create or strengthen social ties of mutual learning and assistance, and sensitivity to disadvantaged groups)?
- the ecological awareness of citizens (e.g. about ecosystem functions and capacities and associated values)?
- the social responsibility of market participants?
- the capacity of participants to be actively involved in deliberations and decision making on public issues?

**Precaution and adaptation for resilience**
How does the operation affect:
- risks of significant damage (e.g. high risk of minor damage, low or ill-understood risks of potentially significant problems) as compared to existing practices and to alternatives?
- capacity for monitoring changes (e.g. by providing good baseline information on initial conditions)?
- the adaptive and precautionary qualities of the island's waste and energy systems (including incorporation of qualities facilitating adaptation in the face of surprise: flexibility, reversibility, diversity, fallback options, and safe-fail characteristics)?
- development of a context and culture of precaution and adaptation?

Does the operation itself have sufficiently robust resilience characteristics (including diverse source and process options, modular components, market alternatives, administrative flexibility and learning capacity) for viability in the face of change and surprise?

**Immediate and long-term integration**
How do the interrelations among the operation's effects influence:
- the delivery or potential for positive feedbacks and mutual reinforcement of desirable effects from the project itself and from other current and reasonably anticipated activities and undertakings?
- the capacity to enhance these positive effects?
- the delivery or risk of negative feedbacks and mutually reinforcing adverse effects?
- the capacity to interrupt and reverse these negative effects?

Table 5 assessment, though not necessarily in directly parallel terms and categories. Initial iterations of the criteria specification and the sustainability–resilience assessment table were completed over a period of several weeks as a joint exercise involving the research team, the interns and the biodiesel workers. Each iteration allowed the expanded research team to understand more clearly the key aspects of and insights from the case at hand. The differences between Tables 4 and 5 reflect the learning process in the iterative elaborations of the criteria development and application in the assessment. The final versions of the two tables were prepared by the research team.

For each consideration, the project's contributions to sustainability are ranked on a simple three-point scale, identifying positive impact (+), negative impact (−), and impact that may be mixed, or positive or negative depending on how it is undertaken (=). For a more advanced analysis, a five-point scale

**Table 5. Key results from the sustainability–resilience assessment**

| | |
|---|---|
| **Social–ecological system integrity and resilience** | |
| Dumping or indefinite storage of toxic wastes materials (methanol, glycerin and washwater) present occupational hazards and locally endanger flora, fauna and groundwater. | − |
| Process has large on-site water requirements (3:1 ratio water to biodiesel) in a water-scarce country; partial mitigation through rainwater harvesting during the wet season is possible. | − |
| Operation takes waste oil out of the waste stream, reducing pressure on very limited landfill capacity. | + |
| Combustion emissions are not significantly less problematic than those from conventional diesel and unlikely to improve air quality. | = |
| Product displaces non-renewable diesel fuel, but requires imported methanol at a ratio of 1L methanol for each 5L biodiesel. | + |
| Main input for biodiesel production is a product of an unhealthy fast and fried food lifestyle. | − |
| Little infrastructure is in place to handle serious disruptions such as failed batches. | − |
| Small-scale production is modular, leading to greater system resilience. | + |
| Local production innovation, with largely local feedstock and local consumption, establishes visible system links for better understanding and management. | + |
| Production could be scaled up for greater impact on long-term resource availability. | + |
| Initiative adds economic diversity to a tourist-oriented economy. | + |
| **Livelihood sufficiency and opportunity** | |
| Diseconomies of small scale limit financial viability. Long-term success requires subsidization, lower input costs, or a willingness by consumers to pay higher prices. | − |
| Employment of three people represents far more jobs per litre of production than in larger scale operations, although current low selling price for biodiesel reduces potential for workers to make a decent income. | = |
| Government subsidy of conventional diesel limits selling price of biodiesel, currently rendering small-scale biodiesel economically uncompetitive. | − |
| Improper handling of toxic materials is dangerous to worker health. | − |
| Further employment along the production chain (e.g. refining glycerin into a value added product) is possible, especially if aggregate production increases. | + |
| There are competing uses for the most desirable waste oil (high quality and/or readily available) including pet food manufacturing and heat generation. | − |
| Multiple small-scale operations could cooperate to gain some economies of scale. | + |
| Small scale and ability for multiple configurations provide potential to produce biodiesel in different contexts and niches. | + |
| The island may be suitable for 5–10 small-scale operations, with many more operations possible if the used oil from cruise ships were made available, or if proper financial incentives were present. | + |
| **Intragenerational equity** | |
| Higher selling price for biodiesel than for regular diesel favours customers who can afford higher product price. | − |
| Desire to encourage biodiesel could help win support for higher fuel prices that would adversely affect lower income residents in the absence of compensatory measures. | − |
| Biodiesel demand is greater than present supply, suggesting potential for expansion and more jobs if more input oil could be found, and if this input use did not supplant more desirable re-uses. | + |
| Both men and women have equal opportunity to produce biodiesel. | + |
| Small operation provides only a small reduction of Barbados' fossil fuel dependence. | = |
| Project has little impact on non-human species other than local flora (where glycerin and wash water may be dumped at times). | = |
| **Intergenerational equity** | |
| Biodiesel contributions should help foster a more self-reliant, diverse and lasting energy supply system. | + |
| Desire to encourage biodiesel could help win support for higher fuel prices that would discourage energy consumption and bring longer term environmental benefits. | + |
| Biodiesel is a good transition fuel to facilitate a move from the current fossil fuel based energy system to a variety of potential future renewable systems. | + |
| Social learning involved in small-scale biodiesel amounts to knowledge development for the next generation. | + |
| Biodiesel reliance on waste cooking oil could delay action to discourage heavy consumption of fried foods to improve long-term population health. | − |
| System has low legacy costs because components can be easily disassembled and used for other purposes and wastes are not persistent hazards. | + |

(*continued*)

**Table 5** (*continued*)

| | |
|---|---|
| **Resource maintenance, feedback and efficiency** | |
| Energy return on investment and the lifecycle energy costs remain uncertain (in part due to limits of assessment data). | = |
| Use of waste vegetable oil as the primary input reduces current resource extraction, and lowers landfill pressure. | + |
| Product partially displaces non-renewable diesel, although it still requires methanol and uses diesel-based electricity. | + |
| Process water demands add to pressures on limited resource. | − |
| Used cooking oil supply vastly exceeds production capacity, although some is low quality (due to over-use), too small a volume to collect, or legally inaccessible (cruise-ship oil). | + |
| Small-scale operation suffers from diseconomies of scale (e.g. methanol input costs and quality control testing). | − |
| Importing methanol to produce biodiesel is not efficient in the long run, but Barbados' fuel cane project could allow switch from methanol-based to ethanol-based biodiesel. | = |
| Small-scale operation has potential to use more energy efficient technologies, such as passive solar heating. | + |
| Biodiesel has multiple uses, including transport fuel, heating and electricity generation. | + |
| Small scale and multiple possible configurations improve modularity and flexibility. | + |
| Physical operation components are quite generic and can often be sourced second hand (e.g. an old water heater as a reactor tank), although some specialized components (e.g. pumps) must be imported. Leads to low upfront resource cost. | + |
| Perceived green benefits of biodiesel may rationalize fuel over-consumption, thereby inducing an undesirable feedback (i.e. efficiency paradox). | − |
| Resilience could be improved by a co-operative of small-scale producers (production could halt at one operation without major effects on fuel supply). | + |
| **Social–ecological civility, networks and governance** | |
| Operation promotes capacity building through community groups (e.g. it was part of the 2008 Parish Ambassador programmes to promote energy independence). | + |
| Process is simple enough that it can be learned relatively quickly. | + |
| Process is an excellent education tool to raise understanding of waste reduction, fuel consumption, CO2 emissions and water use issues. | + |
| Biodiesel production training could be developed and marketed as a green tourism strategy. | + |
| On a small, close-knit island, a successful small-scale operation can affect government policy positively (e.g. building support for decentralized renewable energy production). | + |
| Biodiesel encourages broad involvement of diverse participants (e.g. government agencies, organic farmers, local high school, parish representatives, High Commissions/embassies, restaurants). | + |
| **Precaution and adaptation for resilience** | |
| Project presents low risk of significant damage. | + |
| Conventional diesel remains as a back-up fuel source. | + |
| Lack of accurate data for lifecycle assessments adds some uncertainty to the analysis, requiring ongoing research and adaptive management on the part of all stakeholders. | = |
| Biodiesel production system is flexible enough for physical and operational reorganization, thereby improving resilience. | + |
| Small scale encourages interpersonal communication and tight feedbacks. | + |
| Multiple small-scale biodiesel operations would provide modularity (one could shut down without seriously affecting biodiesel supply) as well as joint savings. | + |
| Social learning aspects of production may encourage culture of conservation. | + |
| **Interactive effects delivering multiple, mutually reinforcing and lasting benefits** | |
| Operation has mostly positive effects on several linked sectors, including waste management, energy security, local employment and economic diversification. | + |
| Biodiesel demonstration may promote a transition from imported non-renewable to domestic renewable energy sources, improving resilience and energy security. | + |
| Knowledge could be exported to other small island developing states in the Caribbean and beyond. | + |
| Example could lead to further attention placed on waste management and water issues and encourage a comprehensive response to both. | + |
| Operation's effects promote social learning in a variety of social–ecological contexts (waste management, energy security, human and ecological health). | + |
| Without proper government support, there is risk of biodiesel operations ceasing on the island (or operating well below potential). | − |

could be used and care taken to avoid overlapping criteria. However, for the case at hand, the purpose was not to sum up all the positive and negative aspects in a quantitative test, but rather to gain broad insights into areas of strengths and weakness, and associated openings for improving contributions to sustainability and resilience.

### *Analysis of the findings: critical themes*

The sustainability–resilience assessment outlined above points to three critical themes — socio-ecological issues, scale issues, and social learning issues — that are not likely to have been revealed so clearly by less broadly framed assessments. The assessment also facilitates identification of a set of promising larger scale options for response to the current limitations of, and opportunities presented by, small-scale biodiesel in Barbados, and these are covered after discussion of the critical themes.

*Socio-ecological issues* While renewable energy and waste reduction reasons are often given for promoting biodiesel and biofuels, the analysis above does not indicate that the Barbados biodiesel operation has strongly positive overall socio-ecological system effects. While the biodiesel operation reduces waste oil volumes sent for landfilling (presuming it would not otherwise go to other competing re-users), and conventional fossil diesel imports to the island, these advantages are compromised by substantial process water requirements in a water-scarce country, production of a waste product that is rarely handled properly, and use of electricity from a grid powered by diesel generators.

*Scale issues* Small-scale biodiesel generally has the capacity to be more dynamic and adaptable, and to engage more stakeholders. Other advantages of small scale include increased resilience due to modularity of design; simplicity of operation; the possibility of physical, operational and institutional reorganization; tighter feedbacks among different stakeholders because more stakeholders are operating in the same level; and increased employment per unit biodiesel produced. Unfortunately, there are also diseconomies of small scale. Small-scale producers, each producing independently, cannot afford to produce biodiesel in Barbados at a competitive price, in part because of the subsidization of conventional diesel and the current lack of subsidies for biodiesel, but also because of the high unit cost of small volume purchases of methanol. Small producers also often lack proper quality control and manage hazardous materials and wastes poorly, in part because of the high unit costs of quality control, material handling and training.

*Social learning issues* Biodiesel is not often promoted or examined for its potential to create networks linking different stakeholder groups and to foster social learning. These benefits are visible in a sustainability and resilience analysis in part because the social learning effects of small-scale biodiesel are not related to the biodiesel end product so much as to the larger biodiesel production system. Furthermore, both scale and socio-ecological systems factors are important to the social learning: the systems provide the context for social learning, while the small scale allows for greater networking with tighter feedbacks. For social learning, biodiesel has several advantages. Biodiesel production involves and can link a great diversity of stakeholders (government, public health, organic farming, schools and restaurants) in a system that raises important national issues, including diet (and health), waste and water management, energy security and economic diversification. As a hub for discussion, biodiesel initiatives can build social awareness of important issues, and also encourage further research into more environmentally friendly production techniques. Because the operations are small, multiple initiatives can be distributed across the island. Moreover, the process is simple enough for use as a learning activity (e.g. by high schools). Finally, with gradual scaling up, biodiesel could be a transition fuel, facilitating a shift from the current transportation and energy infrastructure to more sustainable future options.

### *Analysis of the findings: response options*

The findings of the sustainability–resilience assessment, especially as consolidated in the theme discussion above, point to limitations and opportunities that could be addressed in initiatives beyond the scale of the individual biodiesel operation. Three possibilities are outlined below.

*A co-operative of small-scale biodiesel producers* Barbados could support several small-scale biodiesel producers working together. The co-operative participants could purchase inputs (especially methanol) in bulk to enjoy economies of scale, but still operate their own facilities individually, thereby preserving the tight feedbacks between producers and consumers. Overall biodiesel production would be more resilient because it is unlikely that all the small-scale operations would be shut down simultaneously. Furthermore, larger aggregate glycerin production could supply a viable small-scale operation processing it into biogas (Phalakornkule *et al*, 2009), soap or ethanol. The disadvantage of having multiple producers is they may be competing for the same used cooking oil inputs.

*Government assistance and education expansion* The government of Barbados might take a more active role in biodiesel production by adjusting regulatory control to allow access to used cooking oil from cruise ships, and by subsidizing methanol costs, at least to match its subsidy of conventional diesel. In return, small-scale biodiesel producers might have to extend their education outreach, such as by teaming up with local high schools and community groups to educate citizens of the issues surrounding biodiesel (waste management, energy security, diet, etc.). There is the potential to develop a joint research programme with the University of the West Indies to address the disadvantages of small-scale production (e.g. inadequate quality control). While increased government involvement could reduce the independence of the individual producers, Barbados is a small island, there are few levels of government and bureaucracy to steer through, and government–producer interactions could be positive.

*Biodiesel as a green tourism project* The simplicity, accessibility and socio-ecological benefits of

**The assessment indicated that for the specific context at hand, the main benefit of biodiesel production is in promoting social learning rather than enhancing energy security and waste management**

small-scale biodiesel could be marketed for green tourism on the island. Tourists could pay to learn how to produce *their* own biodiesel, and even donate the final product to disadvantaged local citizens. The added revenue stream from green tourism could offset the high input costs and obviate the diseconomies of small scale. Furthermore, marketing biodiesel as a green tourist attraction would encourage small-scale producers to find innovative solutions for the waste products of biodiesel production. This initiative would tie the fate of biodiesel production to the uncertain future of the tourism industry, but this might be acceptable as a short-term means of strengthening small-scale production infrastructure.

## Conclusion

In principle, an assessment framework that incorporates commitment to meeting sustainability requirements and appreciation of complex system realities is well suited to our times. In practice, its scope is daunting. The illustrative case here demonstrates, however, that a comprehensive but minimally demanding sustainability and resilience based assessment of a modest existing undertaking can be feasible and illuminating.

The assessment indicated that for the specific context at hand, the main benefit of biodiesel production is in promoting social learning rather than enhancing energy security and waste management. It also found that the most promising means of improving the operation lay in larger scale policy and programme initiatives rather than at the project level. Both results can provide insights unlikely to emerge from more narrowly scoped, conventional assessments focusing only on energetic, economic or biophysical concerns.

The broader agenda entails some care in developing a comprehensive set of criteria, specified to recognize the particular issues and system characteristics of the case and context. However, the generic criteria can be drawn from easily accessible sources and the specification can be accomplished without much difficulty using stakeholder knowledge and available published data. Use of these criteria facilitates attention to interrelated issues — especially ones that cross social, economic and ecological boundaries — and identification of broader response options.

The approach described in this paper has some important limitations. Ideally, the kind of sustainability–resilience assessment explored here would be applied iteratively throughout the selection, planning, implementation and closure/renewal of undertakings large and small. In this case, it would have been better if an initial sustainability–resilience assessment had been performed at the beginning of the project, and reviewed several times throughout the life of the project. Furthermore, while the assessment involved key stakeholders in the research process, broader consultation would have added to the legitimacy of the assessment and the plurality of perspectives. Often, however, full-scale application of sustainability–resilience assessment may be prohibitively demanding and unnecessary. What we have illustrated here is an application with ambitious scope that can be completed in a short time with reasonable means and illuminating results.

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## Notes

1. The systems description provides a means of conceptualizing interrelationships amongst actors at various scales in a system whose boundaries are defined by the analyst. Systems descriptions promote the understanding of a situation through multiple perspectives (e.g. social, thermodynamic, economic). Whereas in certain applications (e.g. Waltner-Toews *et al*, 2008) the systems description is undertaken formally, within the present work the systems description served as a means of stimulating transdisciplinary thinking.

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