

Strategic Electric Sector Assessment Methodology under Sustainability Conditions (SESAMS)

Coordinating Technological and Policy Responses to Sustainability and Competition

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Summary

The identification, design and implementation of “sustainable energy systems” is a key element towards successfully approaching “sustainable development.” SESAMS seeks to develop the fundamental strategic analytic capabilities necessary to identify the sustainable production and use of electricity over the next several decades, primarily via the integration of existing and innovative models and analytic approaches as well as those currently under development. In addition to the integration of the requisite models, existing and newly developed databases, performance attributes relevant to sustainable energy production and use will also be developed and refined.

Integral to the development of SESAMS’s analytic capabilities will be an outreach component with stakeholders in select regional energy/electricity debates. Involvement of such multi-stakeholder advisory groups will ensure that SESAMS’s research will not only address sustainability related issues, but link such long-term topics with nearer term concerns such as electric sector liberalization and reductions in greenhouse gas emissions, which currently dominate many policy debates. As increased competition in the electric sector will radically affect energy technology choice and utilization, SESAMS must successfully address the combined issues of *sustainability and competition*. To enhance the effectiveness of SESAMS’s outreach activities, the project will also include the development of decision support tools to assist the formation, communication, and choice of robust technological solutions. Development of analytic capabilities in conjunction with stakeholder audiences will provide a valuable verification function to SESAMS, in addition to providing an avenue to exercise the model and develop better means to interact with the decision-making public and communicate technical information.

This proposal is divided into two parts. The first part describes the larger, longer-term strategy behind SESAMS, and outlines other areas of research at participating Alliance member organizations which will assist, and be assisted by SESAMS. The second part of the proposal, in the Alliance for Global Sustainability (AGS) format, describes Phase I of SESAMS for which Alliance support is requested. In addition, there are several appendices which give more detailed explanations of certain analytic components and ongoing activities.

The proposed work builds upon the current SESAMS-SUP (Start-Up Phase) effort currently supported by ETH and AGS seed money, in 1997, as well as in-kind support from ETHZ, EPFL, the PSI and MIT. Having described the larger sustainability oriented SESAMS architecture, with its coordinated analytic and outreach initiatives, should give a clearer view of the Phase I SESAMS intent and required effort.

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Part One: SESAMS PROJECT

Strategic Overview

1. Introduction / Problem Statement

Many of the issues the world, and the world's energy infrastructure, are facing can be characterized as a combination of:

- 1) *complex problems*
(climate change, air pollution, population growth, degradation of land and water resources, changing standards of living and their in-equitable distribution, globalization of the world's economy, etc.)
- 2) *dispersed solutions*
(infrastructure management and expansion, related but separate actions in the extraction, refinement, transportation and use of energy resources, and the development, deployment and use of new technologies, etc.)
- 3) *finite resources*
(limited access to capital, political and budgetary tradeoffs between the support for education, health, and defense, and the availability of skilled professionals, etc.)
- 4) *societal impacts*
(involving societal groups for ranking options for energy mix technologies, risk aversion, acceptability of individual energy technologies, etc.).

In spite of all our knowledge of science, technology, economics, and social systems, decision-makers in government and industry have rarely been able to focus on the system-wide technological ramifications of their collective decisions, including those which directly address issues regarding the cost-effective and sustainable use of energy. Several near-term areas of particular relevance are the rapid liberalization of energy industries and the possible impacts of greenhouse gas emissions restrictions being considered in international forums. What happens when "climate change meets competition" is a potentially large and important topic. One which most observers will claim to be diametrically opposed to each other. Those overseeing the changes in their respective realms (greenhouse gas restrictions, liberalization of the energy markets) are having a sufficiently difficult time foreseeing the ramifications of their actions individually, let alone collectively. At the same time as countries struggle to identify cost-effective ways in which greenhouse gases can be reduced, they are rapidly eliminating their centralized control and coordination of the electric power industry.

ETHZ, EPFL, PSI, MIT, UT, have designed an interdisciplinary approach to the identification, design and implementation of sustainable systems in the electric sector. SESAMS builds upon each institute's respective areas of expertise, which together form a powerful set of analytic tools for the identification of more sustainable energy/electricity systems under real-world political, infrastructure and economic constraints. Further development and integration of these capabilities to address such new and important topics as sustainable energy use under competition will enable SESAMS to act as a "flight simulator" for decision-makers so that they can assess the impacts of alternative energy choices and policies.

2. The Overall Architecture of SESAMS

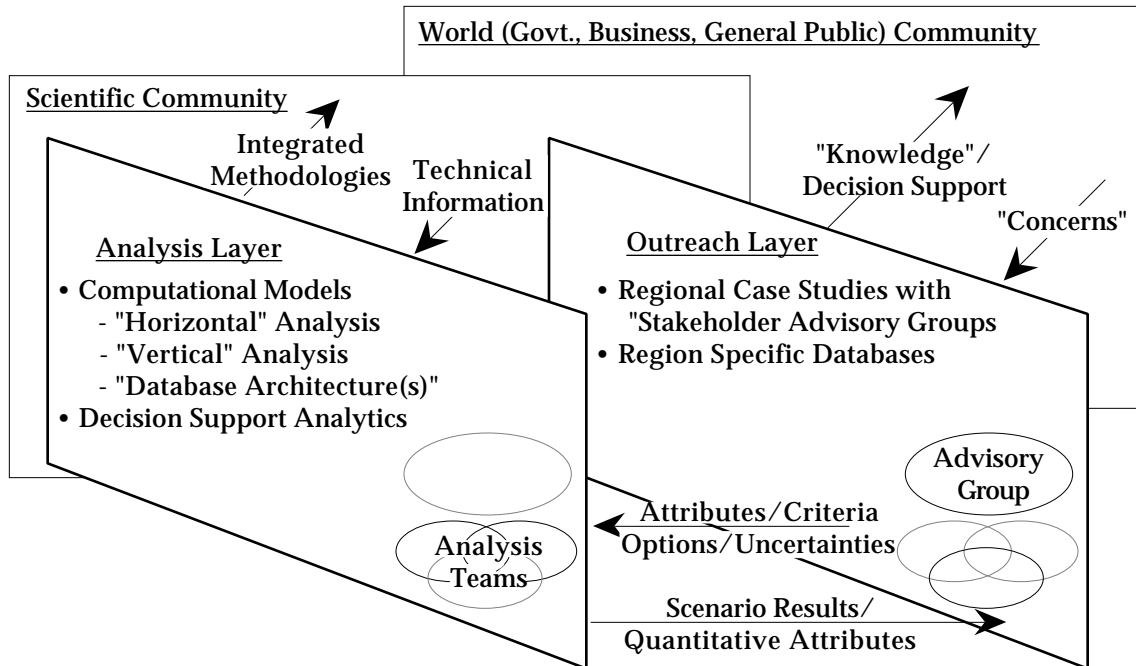
Figure 1.1 presents the overall architecture of SESAMS with respect to its scientific and world communities. These audiences are important since SESAMS must simultaneously advance the scientific and analytic constructs with respect to sustainability and energy system analysis, yet be cognizant of real life goals and constraints, economic, political, environmental, and social in nature.

In Figure 1.1, the scientific and world communities represent both the background, and ultimate audience for SESAMS. Regarding the detailed aspects of the SESAMS architecture, we shall introduce the concepts of: layers and analytic elements.

2.1 SESAMS's Study Layers

As designed, SESAMS is comprised of two distinct interacting layers; the "Analysis Layer" and the "Outreach Layer."

Figure 1.1. Overall SESAMS Framework



The *Analysis Layer* describes the scientific and computational core of SESAMS. As envisioned it is comprised of both Scenario Analysis and Decision Support components. The Scenario Analysis component consists of both a "horizontal" electric system simulation set of analytic tools, and a "vertical" set of life cycle assessment (LCA) analytic capabilities. These will be developed and integrated over time as SESAMS proceeds with regards to the analytic and societal/outreach dimensions of the project. Implicit in the scenario analysis layer is the development of a common "database architecture" which will be filled with regionally specific information depending on the system and/or geographic region under evaluation. The second Decision Support component is comprised of tools and techniques which assist SESAMS researchers in developing scenarios and decision criteria, as well as communicate results from the Scenario Analysis component to the public and identify the best performing set of strategies.

In order to validate and improve the integrated models in the Analysis Layer and disseminate the results, analysis must be exercised in conjunction with an audience of relevant stakeholders. As indicated in Figure 1.1, this second *Outreach Layer* relies upon the use of distinct regional case studies in conjunction with Advisory Groups comprised of multiple stakeholders. These multi-stakeholder groups will be constructed to reflect *inter alia*, society's general "concerns" with respect to energy and sustainable development. SESAMS researchers (grouped into their functional "analysis teams") will interact with the advisory groups, and actively incorporate the advisory groups' attributes/criteria and options/uncertainties into the analytic methodologies and scenarios.

Successful execution of the scenario analysis allows the analysis teams to report back to the advisory groups scenario results and their various implications. Decision-makers' improved understanding of the consequences of their actions are ultimately reflected in their decisions, and their communications to society-at-large. It is anticipated that SESAMS can and will assist in these efforts *via* further dissemination of scenario results, but more importantly, *via* the further development of decision-support tools, exercised *via* the case studies.

2.2 SESAMS's Major Analytic Elements

The three major analytic elements of SESAMS are:

- 1) Horizontal Scenario Analysis,
- 2) Vertical Scenario Analysis, and
- 3) Decision Support Analysis.

Figure 1.2 illustrates how these three analytic capabilities are coordinated and are enhanced through time. Also illustrated are the anticipated development stages of SESAMS, beginning with the current start up (SUP) phase, the first phase (for which this proposal requests funding), and subsequent phases (see Appendix 4).

As can be seen the horizontal scenario analysis layer focuses on the continued development of electric sector analysis tools. While the figure emphasizes the evaluation of conventional, evolutionary, and revolutionary supply and demand-side technologies, factors effecting technology choice and utilization, such as those imposed by alternative competitive structures, and greenhouse gas emissions taxes or emission constraints will be considered in the choice and/or development of "horizontal" analytic and simulation tools. The vertical, life cycle assessment scenario analysis layer builds upon the horizontal scenario analysis layer by calculating the materials consumption and upstream/downstream emissions levels associated with a scenario's electric sector technology choice and utilization profile. Coordination and integration of the horizontal-resource planning and vertical-life cycle assessment analytic steps is key to the development of informative attributes reflecting a strategy's performance with respect to sustainable energy use. Essential to the successful application of SESAMS to new regions will be the ability to generalize the current LCA analytic approach in order to evaluate different specific sustainable development strategies.

One of the challenges that SESAMS faces is the development of an analytic structure that can be used to evaluate inherently different energy/electricity infrastructures. Table 1.1 lists the various types of energy infrastructures for which alternative paths to "sustainable energy" will need to be developed. While the databases of future technologies can be considered global in nature, imbedded electricity production and energy-use infrastructures, rates of economic growth, electric sector liberalization and energy consumption (and therefore rates of new energy technology penetration) are region specific. In the long-run, SESAMS should seek to explore all of these categories via related case studies, preferably with respective associated advisory groups.

Currently there are two case studies (Switzerland and New England, USA) for which the initial elements of SESAMS have been applied. Under SESAMS Phase I these two case studies will be continued to further exercise SESAMS model integration and decision support enhancements. Both regions are sufficiently dissimilar in imbedded infrastructure, and political decision-making and regulatory environments to provide broader guidance in the selection of additional illustrative case studies. However, once Phase I is completed, additional regions for exploration should be evaluated, with additional outside funds. Ultimately a case-study led by each participating institution will help each university and lab develop a full range of analytic capabilities, even though the development and refinement of various horizontal, vertical and decision-support techniques may be spearheaded by a specific individual institution.

Figure 1.2: SESAMS's Major Analytic Components

SESAMS Phases ->	SUP	Phase I	Phase II	Phase 'n'
<u>Horizontal Scenario Analysis</u> (Electric Sector Analysis)			Revolutionary	
		Evolutionary		
<u>Supply/Delivery</u>	Conventional			
<u>Demand/Consumption</u>	Conventional			
		Evolutionary		
			Revolutionary	
<u>Vertical Scenario Analysis</u> (Life Cycle Assessment)				Economic & Social Costs
			Environmental and other Impacts	
<u>Life Cycle Assessment</u>	Inventory (Consumptions & Emissions)			
				Multi-Criteria Optimization
<u>Decision Support Analysis</u>	Multi-Criteria Decision Analysis			
<u>Decision Analysis/Support</u>	Multi-Attribute Tradeoff Analysis			

Table 1.1: Types of Integrated Energy Infrastructures

<u>Energy Infrastructure Type</u>	<u>Rate of Infrastructure Growth</u>	<u>Size of Existing Infrastructure</u>	<u>Age of Existing Infrastructure</u>	Example(s)
Mature/Industrialized	Slow	Large	Moderate/Aged	OECD
Re-Industrializing	Slow/Moderate	Large/Medium	Aged/Moderate	FSU, E. Europe
Emerging/Industrializing	Rapid	Small/Medium	Moderate/New	China, India
Less Developed	Slow to Rapid	Small	Aged/Moderate	Africa

The key deliverables from SESAMS will be numerous. In addition to the enhanced horizontal, vertical, and decision-support tools will be the centralized databases of future conventional, evolutionary and revolutionary technological options, databases describing various regions' existing generation and electricity consumption characteristics, and finally a rich set of analytic results describing various regions' electric industry alternatives and their relative performance for a wide range of criteria. These deliverables will represent a scientifically challenging and unique set of analytic tools and information, to help key electric industry decision-makers in the case-study regions and elsewhere.

The following sections describe each of the three analytic elements in more detail, and describe how each component is coordinated in topic and time with the other analytic tasks. These sections also describe how each task leverages, or is leveraged by, other ongoing research at each academic institution including other AGS initiatives, and how SESAMS has been staged through time so that useful results, and analytic improvements can be developed given realistic financial constraints. The following sections refer directly to the analytic tasks and timetables illustrated in Figure 1.2.

2.3 Horizontal Scenario Analysis - Regional Electric Sector Simulation

Horizontal electric sector analysis employs resource planning tools to simulate the cost, reliability, and environmental/emissions performance of a regional power system. Industry standard computer models are currently being used in SESAMS-SUP and for the New England case study, to simulate the performance of regional strategies for various mixes of electricity supply and consumption technologies. To date, the capabilities of commercial “production costing” models have been enhanced by SESAMS team members with pre, parallel and post processing of various technological options such as non-dispatchable renewable energy options (solar photovoltaics and wind), more energy efficient uses of electricity, new demand-side “electrotechnologies” such as electric vehicles, inclusion of “environmental externality” cost factors, and the calculation of an extensive range of decision and strategy performance attributes.

However, strategies recently under evaluation in SESAMS-SUP and at MIT have focused on the best currently available commercial technologies, and only for the next two or three decades. SESAMS therefore intends, if appropriate resources are available, to extend the duration of the regional electric sector simulations and broaden the range of technologies under consideration to include “evolutionary” and “revolutionary” generation and supply technologies. In Figure 2, these two types of technologies are italicized to reflect that while SESAMS will utilize the descriptions of such technologies in their electric sector analysis, the development and technological characterization of such technologies will be “imported” into SESAMS from sister Alliance projects, related work at participating SESAMS institutions, and from published works in general. This is one of the primary avenues whereby sustainable energy strategies will first be evaluated.

Not illustrated in Figure 1.2, but instrumental to the innovative aspects of SESAMS, are issues related to the competitive market, climate change mitigation, policies promoting the sustainable use of energy. Past horizontal analysis has shown that technology choice AND utilization together are the key aspects of how well given technologies perform with respect to costs, emissions, etc. Enhancement of existing production costing models, or the adoption of a new power system simulation model which allows SESAMS researchers to simulate the influence of alternate competitive structures on the utilization of new and existing generating technologies is key to identifying possible sustainable energy mixes which meet the combined goals of industry liberalization and substantial and sustained reductions of greenhouse gases (GHG) and other environmental pollutants (see also Appendix 1). The ability to simulate, and therefore evaluate, alternate environmental initiatives such as GHG emissions trading, carbon taxes, etc. are additional enhancements that are required for SESAMS analysts to provide real and informative assessments to industry and governmental stakeholders.

Unlike many energy-economy studies which have the “flavor” of SESAMS’s horizontal analytic approach, SESAMS will employ a systems analysis approach. Past work has shown that such an engineering “bottoms up” approach is a superb complement to many of the econometric “top down” studies that have been performed, since they deal directly with the technological response precipitated by a given policy, an emissions tax, or prohibition on a given technology. The fact that such an engineering analysis approach is used to evaluate a broad range of possible energy policy and technology choices provides the stakeholder audience guidance on what are, and are not, superior performing mixes of energy technologies. They are also useful for identifying technologically, but not politically feasible energy strategies. Politically feasible, but technologically inferior strategies are also identified and communicated to decision-makers.

SESAMS therefore intends to take existing and developing data and models and evaluate alternate energy paths for the project’s various decision-maker audiences.

2.4 Vertical Scenario Analysis-Life Cycle Assessment (LCA) of Horizontal Strategies

The horizontal scenario analysis component, while making great strides in the inclusion of potentially sustainable technologies and energy use policies, is insufficient, in and of itself, to demonstrate the degree of compliance with a robust set of sustainability related performance criteria. For this reason SESAMS will further integrate the resource planning enhancements described above with the Life Cycle Assessment capabilities developed at PSI and ETHZ. These capabilities, best reflected by the GaBE initiated research will need to be enhanced and extended beyond their current state, which has been tailored to the Swiss energy sector. (A discussion of such activities is included in Appendix 2.)

As illustrated in Figure 1.2, the current LCA tools will be applied to select superior performing strategies currently being evaluated in the SESAMS-SUP project. Extension of these databases will be required so similar calculations may be made within SESAMS for the sister New England case study, and to evaluate the broader range of technology options mentioned above. Calculation of these material and emissions inventories is the first goal of the LCA efforts in SESAMS.

This geographic and technological extension of the LCA tools, and the calculation of differentiated inventories, is the core thrust of the LCA effort under SESAMS Phase I. As noted in Figure 1.2, long-term goals within SESAMS's analytic thrust is the eventual extension of the scope of work beyond LCA environmental inventories to include health and environmental impacts, and costing of these normally external impacts for use in the economic calculations. Such extensions ARE NOT being considered for full scope implementation within SESAMS Phase I due to the extraordinary analytic requirements in terms of site specific data, data quality, personnel, and ultimately overall cost. Nevertheless, some impacts associated with the considered electricity generation systems will be explicitly addressed and compared. Full implementation of these tasks can hopefully be pursued if SESAMS continues forward, or via research projects parallel to SESAMS at the participating institutions.

The estimation of total energetic and non-energetic resource consumption and pollutant emissions (gaseous, liquid and solid), provides a solid foundation for first order assessment of whether a given electric sector energy strategy is "sustainable" from the environmental point of view, and if not, by how much. The ratio of limited natural resources consumed-to-recycled and inexhaustible material consumption could be used as a primary indicator of sustainability. Year to year tracking of this ratio for a given energy strategy indicates whether the strategy is "on the path to sustainability." Calculation of total resources and materials consumption, as well as its consumption of limited natural resources, is important as a strategy which uses more total materials than another, but with a much lower fraction of virgin material consumption, may be considered significantly more sustainable (or more appropriately less unsustainable) than a strategy which uses less overall materials, but significantly more of limited natural resources.

2.5 Decision-Support Analytics

The reader will no doubt recognize the ultimate breadth and level of detail incorporated into the above scenario analysis components. Communicating the characteristics of the numerous technologies, their combination into strategies, the various policy constraints, the range of future uncertainties with respect to the economy, as well as the multitude of performance criteria calculated in the scenario analysis phase is a daunting task. Communicating what the results mean to an often non-technical stakeholder audience is even more daunting, but has been demonstrated feasible in both SESAMS-SUP and in previous work, most notably at MIT with the Analysis Group for Regional Electricity Alternatives (AGREA), and at EPFL with stakeholder group associated with the *Filières* studies.

The AGREA approach, generally referred to as “multi-attribute tradeoff analysis” (MATA) has been used to successfully communicate technical results to, and facilitate a dialogue among, stakeholders with different views and responsibilities in the public sector. While the use of such computer assisted dynamic graphing technique is pedagogically very effective, enhanced tools are required when more than just education on alternatives is required. The Decision-Support analytics to be developed and applied in SESAMS build upon the techniques developed at various groups in the ETH network.

Techniques to be employed include, but are not limited to, the crafting of improved decision criteria from the stakeholder point of view. Examples of such enhancements include the conversion and aggregation of scenario performance attributes into improved decision criteria, the ranking and weighting of attributes and performance criteria to reflect the perspectives of “society” and individual stakeholder groups, the incorporation of risk preferences, and processes to develop new tailored sets of scenarios for further analysis ⁶.

3. SESAMS Phase I Case Studies and General Outreach

As indicated above, development and application of the proposed SESAMS tasks are only worthwhile if they can be used to promote a better understanding of our energy alternatives and requisite technological and policy requirements to stakeholders. Interaction with a select set of stakeholders (commonly referred to as “The Advisory Group”) also assists the verification of the analytic models and their component databases, technical assumptions and descriptive criteria. Interaction with an Advisory Group is an essential components of the research’s outreach effort, as the level of detail and complexity involved in the technical studies requires a longer-term commitment on behalf of the stakeholder audience. Presenting, and discussing the implication of the results with the stakeholder group helps researchers distill the analytic results for communication to the general public ⁷.

⁶ Experience has shown that such enhanced decision-support tools are necessary when stakeholder group responsibilities move from understanding the relative performance of alternative energy strategies, to actually choosing a strategy to pursue, or policy to adopt and promote. In Figure 2, this transition is reflected by the parallel decision support activities of multi-attribute tradeoff analysis, and multi-criteria decision analysis. It is necessary to note however that successful use of such methods with actual groups of stakeholders requires appropriate execution of the scenario analysis activities. Interaction with actual industry stakeholders is also required if real-life preferences and attribute weighting criteria are to be incorporated. Further efforts are needed to penetrate or introduce such tools into ongoing policy discussions (e.g. *Swiss Energy Dialogue*).

⁷ For Phase I of SESAMS, the current Swiss and New England advisory groups should be maintained, with perhaps the addition of some new select stakeholders. Maintenance of local stakeholder groups for the initial phases of the project will reduce the overhead of model enhancement, and the testing and verification of those enhancements with a policy audience. As mentioned in the overview, once a reasonable robust analytic structure is in place, additional case studies, particularly for developing and/or re-industrializing regions should be pursued.