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Evaluation Framework and Tools for Distributed Energy Resources

Etan Z. Gumerman, Ranjit R. Bharvirkar,
Kristina Hamachi LaCommare, and Chris Marnay

Lawrence Berkeley National Laboratory
1 Cyclotron Road., MS90-4000
Berkeley, California 94720

Environmental Energy Technologies Division

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Evaluation Framework and Tools for Distributed Energy Resources

Prepared for the
Distributed Energy and Electric Reliability Program
Assistant Secretary for Energy Efficiency and Renewable Energy
U.S. Department of Energy

Principal Authors

Etan Z. Gumerman, Ranjit R. Bharvirkar, Kristina Hamachi LaCommare,
and Chris Marnay

Ernest Orlando Lawrence Berkeley National Laboratory
1 Cyclotron Road, MS 90-4000
Berkeley CA 94720-8061

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Glossary

AEO2002	Annual Energy Outlook 2002
CHP	combined heat and power
CT	combustion turbine (also called gas turbine)
DEER	Distributed Energy and Electric Reliability Program of DOE
DER	distributed energy resources (in this work, specifically customer-controlled on-site generating assets of . 500 kW)
DOE	U.S. Department of Energy
EIA	Energy Information Administration
FERC	Federal Energy Regulatory Commission
GHG	greenhouse gas
GW	gigawatt (10^9 watts)
Hg	mercury
kW	kilowatt (10^3 watts)
LMP	locational marginal prices
MW	megawatt (10^6 watts)
NGCC	natural gas combined cycle
NIMBY	not in my backyard
NO_x	nitrogen oxides
PM	particulate matter
PV	photovoltaic
PURPA	Public Utilities Regulatory Policies Act
RMI	Rocky Mountain Institute
RPQ	reliability and power quality
RTO	regional transmission organization
SO_2	sulfur dioxide
SOAPP	state-of-the-art power plant
TAF	tracking and analysis framework
T&D	transmission and distribution
TSI	total societal impact

Executive Summary

The Energy Information Administration's (EIA) 2002 Annual Energy Outlook (AEO) forecast anticipates the need for 375 MW of new generating capacity (or about one new power plant) per week for the next 20 years, most of which is forecast to be fueled by natural gas. The Distributed Energy and Electric Reliability Program (DEER) of the Department of Energy (DOE), has set a national goal for DER to capture 20 percent of new electric generation capacity additions by 2020 (Office of Energy Efficiency and Renewable Energy 2000). Cumulatively, this amounts to about 40 GW of DER capacity additions from 2000-2020. Figure ES-1 below compares the EIA forecast and DEER's assumed goal for new DER by 2020 while applying the same definition of DER to both. This figure illustrates that the EIA forecast is consistent with the overall DEER DER goal.

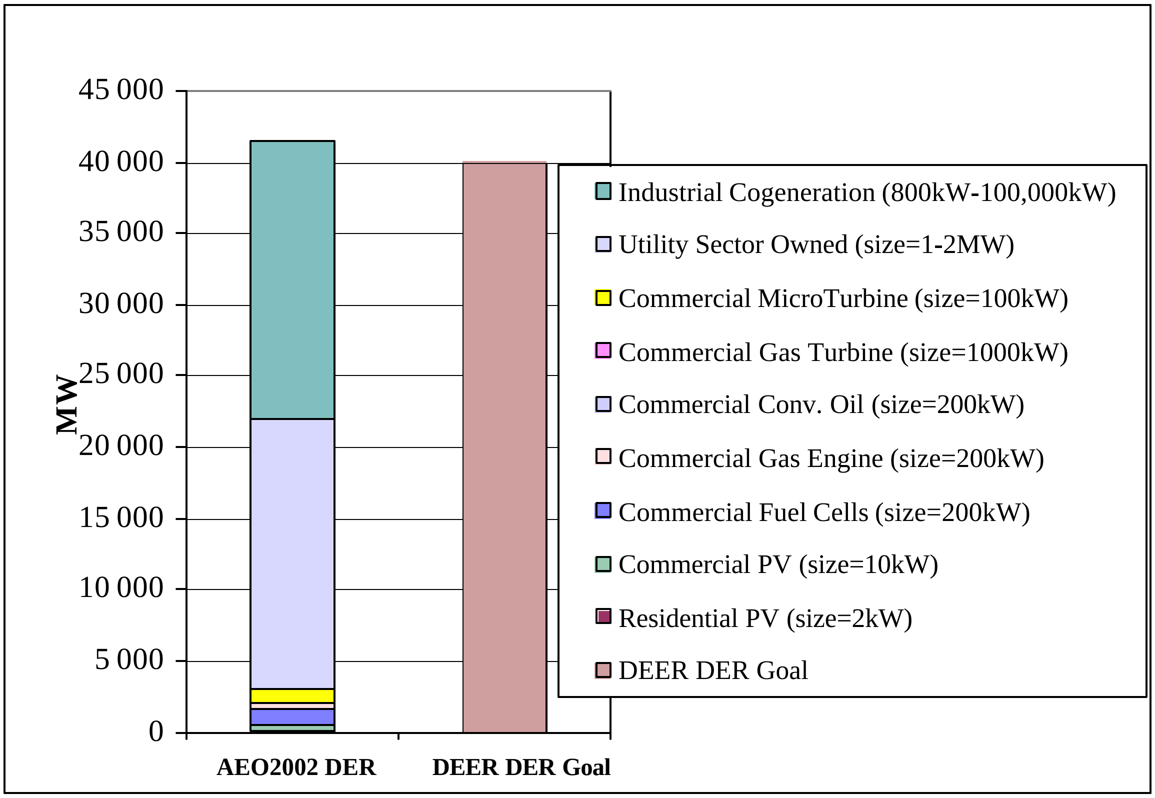

Figure ES- 1. DER capacity additions by 2020, by Forecast and Target

For the purposes of this study, Berkeley Lab needed a target level of small-scale DER penetration upon which to hinge consideration of benefits and costs. Because the AEO2002 forecasted only 3.1 GW of cumulative additions from small-scale DER in the residential and commercial sectors, another approach was needed to estimate the small-scale DER target. The focus here is on small-scale DER technologies under 500 kW. The technology size limit is somewhat arbitrary, but the key results of interest are marginal additional costs and benefits around an assumed level of penetration that existing programs might achieve. Berkeley Lab assumes that small-scale DER has the same growth potential as large scale DER in AEO2002, about 38 GW. This assumption makes the small-scale goal equivalent to 380,000 DER units of average size 100 kW. This report lays out a framework whereby the consequences of meeting this goal might be estimated and tallied up. The framework is built around a list of major benefits and a set of tools that might be applied to estimate them.

Many of the benefits and costs of DER accrue to people other than those who decide to install DER systems, incur its direct costs, and claim its direct benefits. Economists call these effects *externalities*. Unless externalities are accounted for by identifying the gainers and losers and charging/compensating them accordingly, they form one of the classic forms of market failure. In other words, unless markets or regulatory structures are instituted so that the full range of costs and benefits accrue to the investor in DER, s/he is unlikely to make the optimal social investment choice. The notion of total social impact (TSI) is built on the simple belief that an accounting of social costs and benefits could be made for DER and the optimal social decision found. Clearly, such a calculation involves imponderables too numerous to explore fully here. Nevertheless, this idea provides a useful framework beginning an enumeration of the benefits, laying out the important unknowns, considering the tractability of calculating the effects, and evaluating the usefulness of the tools at our disposal.

This study lists some of the major effects of an emerging paradigm shift away from central station power and towards a more dispersed and heterogeneous power system. Seventeen societal effects of small-scale DER are briefly summarized. Each effect is rated as high, medium or low, on three different scales that will help determine the optimal social investment. The three scales are: the magnitude of the economic benefit; the likelihood that the benefit can be monetized in efficient markets, i.e. internalized; and how tractable it might be to quantify each benefit analytically. Some of the modeling tools that may be used to estimate these effects are described in the Appendix.

The effects that are considered large are naturally of particular interest because they have a significant bearing on the TSI. The likelihood that markets can and will internalize the cost or benefit is of interest because it indicates whether public policy needs to intervene to internalize benefits or costs. And finally, the tractability is intended to indicate how much analytic effort might be needed to estimate the benefit. These ratings should provide some guidance on which effects one might attempt to estimate first. For example, large benefits are clearly candidates for estimation even if they are fairly intractable. The two most tractable effects are “Lower cost of electricity” and “Combined Heat and Power/Efficiency Improvement” (effect numbers 1 and 4). The latter is also of particular interest because of the policy importance of increasing overall energy efficiency and lowering carbon emissions. Effects with low market likelihood and high tractability are interesting for policy purposes, making estimation of ”Reduced Transmission Losses” (effect number 10) an appealing early challenge.

Table ES- 1. Each effect is rated as high, medium or low, on three different scales that will help determine the optimal social investment. The three scales are: the magnitude of the economic benefit; the likelihood that the benefit can be monetized in efficient markets, i.e. internalized; and how tractable it might be to quantify each benefit analytically. Some of the modeling tools that may be used to estimate these effects are described in the Appendix.

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Table ES- 1. Summary of DER Effects

	Benefits and Costs	Economic Magnitude	Market Likelihood	Analytic Tractability
1	Lower Cost of Electricity	$$, $$$	***	###
2	Consumer Electricity Price Protection	$, $$	***	##
3	Reliability & Power Quality[1] (RPQ)	$$ $, $$	*** *	## #
4	Combined Heat and Power/ Efficiency Improvement	$$$	***	###
5	Indoor Emissions	-$	*	##
6	Noise Disturbance	- $	*	##
7	Consumer Control	$	***	#
8	Electricity T & D Deferral and Congestion Relief	$$$	**	##
9	Capacity Deferral and Increase in Stranded Assets[2]	+/-$$	*	##
10	Reduced Transmission Losses	$	*	##
11	Voltage Support to Electric Grid	$, $$	*	#
12	Reduced Security Risk to Grid	$$	*	#
13	Enhanced Electricity Price Elasticity	$, $$	*	#
14	Airborne or Outdoor Emissions[2]	+/- $$	*	##
15	DER Fuel Delivery Challenges	-$, -$$	**	##
16	NIMBY Opposition to New Central Power Plants & Transmission Lines	$	*	#
17	Land Use Effects	$	*	##

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[1] This effect has two different aspects and two sets of rankings. The first is for RPQ benefit to DER owner. The second is RPQ benefit to utility and regional customers. Note that the benefits to the wider power system are highly uncertain both because the direct benefits are not easily known and because there may be highly uncertain secondary benefits, such as enhanced ability of the economy to tolerate low quality grid power. These are explained in section 3.1.3.

[2] This effect may be a benefit or a cost, therefore +/- is used to describe the economic magnitude.

1. Introduction

It is quite likely that the U.S. power system will undergo a major paradigm shift over the next quarter century. Through the 1970's, the industry was characterized by an inexorable march towards larger generating stations controlled over larger areas by a highly centralized control structure, with the entire system in the ownership of territorially defined, vertically integrated utility companies. The philosophy of this system was to provide high universal quality of service to all customers at low cost. Centralization of control and transmission over long distances permitted utilities to capture low cost sources and economies of scale, while diversifying risks. In some ways this process still continues, for example in FERC's efforts to form regional transmission organizations (RTO's).

The first stage counter to this centralizing process was marked by passage of the Public Utilities Regulatory Policies Act of 1978 (PURPA). PURPA required monolithic utilities to buy power from independent generators, if they met certain criteria. The second stage is the ongoing restructuring of the industry, which began in the mid nineties, and the third may be the emergence of distributed energy resources (DER) as competition with traditional central station power.

In most cases, DER will be economically attractive either because of the capture of waste heat in combined heat and power (CHP) systems, or because of the power reliability and quality requirements that deviate from the universal standard. Of course, there are other reasons why DER generation may be worthwhile from the customer perspective. While DER generators are unlikely to compete with central station power based on thermal efficiency alone, customers will be attracted by the gap between wholesale and retail electricity prices (up to 8 ¢/kWh in some U.S. markets), the desire for specialized power quality or reliability, and by other less tangible attractions.

The Office of Distributed Energy and Electric Reliability (DEER) within the Department of Energy (DOE) has included in its strategic plan the goal of making the nation's energy generation and delivery system the "cleanest and most efficient, reliable and affordable in the world by maximizing the use of cost efficient distributed energy sources" by the year 2020. By 2020, DEER's goal is to reduce costs and emissions while increasing the efficiency and reliability of a suite of DER technologies to capture 20 percent of new electric generation capacity additions (Office of Energy Efficiency and Renewable Energy 2000).

While the definition of DER varies considerably across analyses, in its consideration of the benefits and costs of DER, this study is focused on small on-site power generation from units of a few kW to 500 kW in size. These sources would typically be too small to be considered by commercial generators in the existing power system. For example, typically, only sources of 1 MW, or greater, can participate in existing electricity or ancillary services markets. EIA and DEER do not distinguish between "small-scale DER", up to 500 kW, and "large-scale DER," greater than 500 kW. In this paper, we use "DER" and "small-scale DER" interchangeably. The terms "large-scale DER" and "total

DER", which means both DER and large-scale DER, will be used as necessary to avoid confusion.

DOE's Energy Information Administration (EIA) has forecast in its *Annual Energy Outlook 2002* (AEO2002) reference case scenario that a total of 375 GW of increased generating capacity (including cogenerators) will be needed to meet growing electricity demand and to offset retirements between 2000 and 2020. Of the new capacity, 83 percent is projected to be either natural gas fired combined cycle (NGCC) or combustion turbine (CT) technology. A total of 31 GW of new coal-fired capacity (or 8 percent of total new capacity) is projected to come on line between 2000 and 2020. Non-hydro renewable technologies (primarily wind, geothermal, and municipal solid waste units) account for 4 percent of expected capacity expansion by 2020. The remaining 19 GW represents a majority of the total DER in NEMS coming from large-scale utility-owned DER. There is 3 GW of DER represented as smaller-scale residential and commercial sector installations which is counted within renewables or gas-fired new capacity. EIA considers fuel cell capacity (less than 1 GW in forecast), as DER.

Based on the AEO2002 projections for new capacity additions, Berkeley Lab interprets the DEER goal to imply approximately 40 GW of new DER capacity must be installed by 2020. Figure 1 illustrates how a cumulative total of 40 GW is calculated from AEO2002's forecast of 375 GW of new capacity.

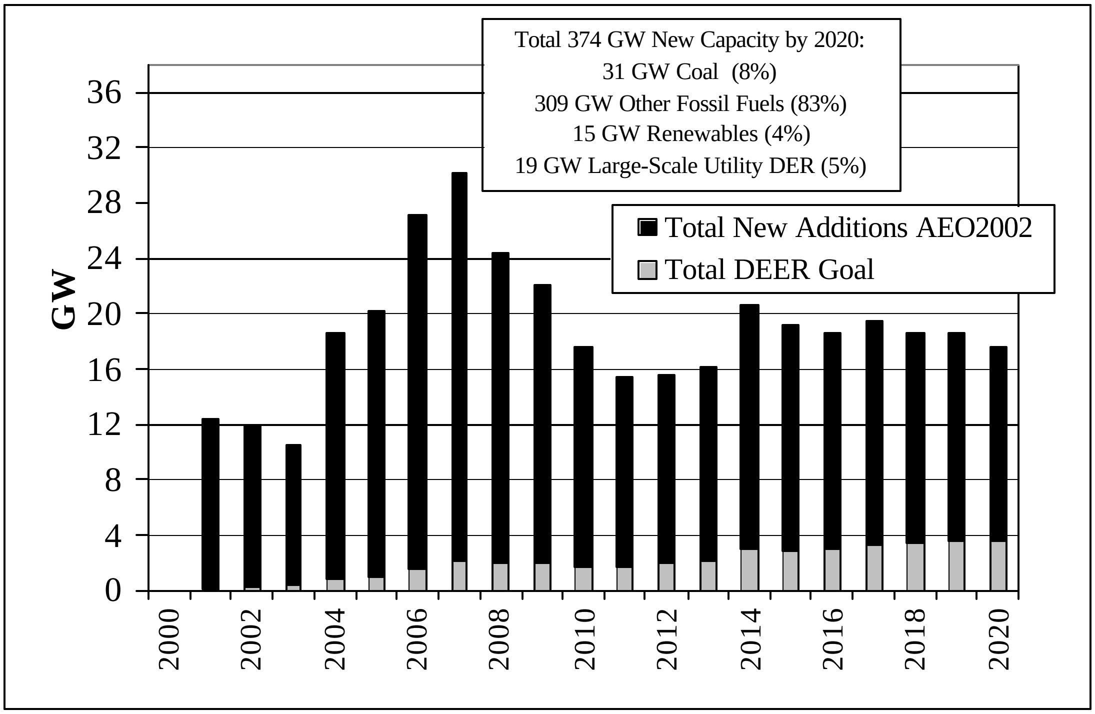

Figure 1. AEO2002 New Capacity Additions with DEER Goals

The black shading represents the additional capacity installed each year by electric generators and cogenerators. The graph is formatted such that the bars are overlain not stacked. For example, in year 2007 the total incremental capacity additions from AEO2002 are 30 GW, not 30 GW minus the approximate 2 GW from the gray bars.

The black bar magnitudes, which sum to 375 GW, come directly from the AEO forecast. The DEER goal is superimposed in gray denoting the amount of total new capacity that is expected to come from DER sources. Berkeley Lab calculates the values for the solid gray bars based on the assumption that DEER's goal means that 20 percent of capacity installed in 2020 will be from DER, not that DER will contribute 20 percent of all cumulative new capacity between 2000 and 2020. Therefore, the solid gray bars show the interpolated DEER goal assuming 1 percent of new capacity in 2001 from DER, 2 percent of new capacity in 2002 and so forth escalating to 20 percent in 2020. The sum of all the solid gray bars, across all years, represents the DEER DER goal of 40 GW.

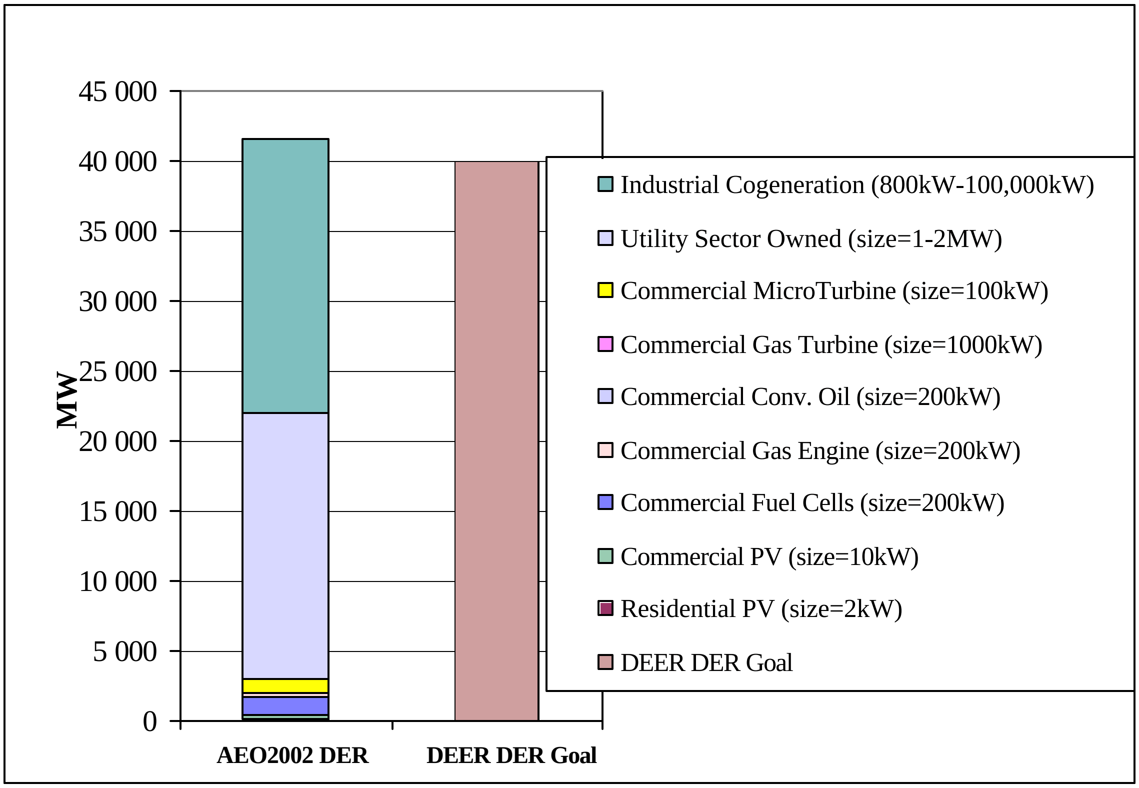

Figure 2. DER capacity additions by 2020, by Forecast and Target

In contrast to DEER, AEO forecasts 22 GW of total DER, just over half of DEER's goal. However, in order to accurately compare AEO's forecast to DEER's goal, their different definitions of DER must be reconciled. The AEO includes fuel cells and photovoltaics (PV) in its definition of DER, while excluding industrial and commercial cogeneration. Interestingly, if AEO were to use DEER's DER definition, their DER forecast would also be 40 GW by 2020. This is mostly because the AEO forecasts 19.5 GW of new cumulative large-scale cogeneration capacity by 2020. Figure 2 compares EIA's forecast and DEER's total DER goal both using a wide and consistent definition of total DER. These values are almost identical, that is, the AEO forecast is consistent with the DEER goal for total DER.

Currently, the AEO forecasts that over 90 percent of new total DER will be large-scale by the definition used here, and a considerable share comes from industrial units up to 100 MW.

Figure 2 shows 3 GW of small-scale DER, and 38 GW split almost evenly between large-scale industrial cogeneration and utility-sector owned DER. While many of the benefits from small-scale DER and large-scale DER are the same or overlapping, Berkeley Lab chose to anchor this analysis with a small-scale DER target for 2020. Therefore, this analysis is based on the working assumption that small-scale DER could make up as much as 50 percent of new total DER generation by 2020, i.e. roughly equal what AEO forecasts for large-scale DER by 2020. Based on this target, the net small-scale DER contribution that this study focuses on is about 38 GW by 2020, and since this target is a soft number anyway, it is hereby rounded up to 40 GW. Assuming the average generator size is 100 kW, this estimate suggests about 400,000 generators installed by 2020. This level of market penetration is a significant increase over what AEO2002 forecasts. The purpose of the preceding back-of-the-envelope forecast is merely to place consideration of the consequences of achieving the DEER goal into a clearer focus. In other words, the marginal benefits and costs of DER need to be estimated marginally around some target, and for the purposes of this study, that target is 40 GW of total cumulative installed capacity.

There are a number of reasons why DER is not becoming more rapidly adopted. One problem often mentioned by analysts is that an individual makes the decision of adopting DER based only on a partial accounting of benefits and costs that affect him or her as an individual and not the society in general. In other words, decisions are made on the basis of direct costs only. It should be the legitimate purview of public policy to create incentives that move adoption decisions closer to the social optimum, i.e. one based on a full accounting of costs and benefits both internal and external. However, before policies can be formulated, the social optimum must be found based on a full accounting of the effects of DER.

This report will try to suggest routes to answering some of these initial difficult questions: What are the consequences of meeting DEER's 20 percent goal? How important are these effects? And how could their full societal value be estimated? This study lists some of the major effects of an emerging paradigm shift away from central station power and towards a more dispersed and heterogeneous power system. Then some of the modeling tools that may be used to estimate the effects are described.

Many DER effects that are being overlooked or wrongly valued have the potential of changing the cost-effectiveness of DER adoption substantially. The Rocky Mountain Institute (RMI) estimates that a full accounting of the benefits of DER typically raises their value by as much as ten-fold (Lovins et al. 2002).[3] Such a market imperfection contributes to the sub-optimal pace of DER adoption. In some classic DER cases, the effect is clear and obvious. For example, small-scale rooftop PV generation provides clean power close to demand, usually at times of high system load, and contributes to the

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[3] RMI notes that the actual increase depends strongly on each case, site, and timing of DER adoption.

overall energy efficiency of the economy thereby reducing carbon and pollutant emissions and fostering energy independence. Yet absent net metering laws and/or other subsidies, many of the economic benefits of PV would not accrue to the installer, and even net metering does not accurately present incentives, because he or she is unlikely to ever precisely capture the environmental benefits, or the benefit of secure supply. In other cases, the DER installer may be over compensated; for example, a DER installation using a subsidized fuel might yield greater returns to its owner than are justified. However, in most cases, the picture is much more confusing than these examples, and in all cases actually quantifying the effects is a daunting task.

To help organize the numerous effects into a general framework, the next chapter describes a framework for evaluating both direct and indirect value components and applies a hypothetical value, the total societal impact (TSI). The TSI is simply the sum of all internalized benefits and costs. Depending on the reader’s interests, this method could be used to evaluate a single DER installation decision, or the regional effects of widespread DER adoption.

2. Total Societal Impact Framework

Many of the benefits and costs of DER accrue to people other than those who decide to install DER systems, incur its direct costs, and claim its direct benefits. Economists like to call these effects *externalities*. Accounting for externalities involves identifying the gainers and losers and charging/compensating them accordingly. Failing to account for externalities is one of the classic forms of market failure. In other words, unless markets or regulatory structures are instituted so that the full range of costs and benefits accrue to the investor in DER, s/he is unlikely to make the optimal social investment choice.

The notion of total social benefit (TSI) is built on the simple belief that an accounting of social costs and benefits could be made for DER and the optimal social decision found. Clearly, such a calculation involves imponderables far too numerous to contemplate at this stage, nevertheless this idea provides a useful framework for enumerating the benefits, laying out the important unknowns, considering the tractability of calculation of effects, and a cursory evaluation of the usefulness of the tools currently at our disposal.

In this report, three classes of DER beneficiaries are considered: the individual or business that installs the DER unit; utilities or electricity generators; and the community and larger region surrounding the site. This report defines 17 benefits and costs, classified by primary beneficiary. Each benefit is described in Section 3. The aim is to describe the effect, to identify to whom it might accrue, to speculate how significant it might be, and to consider how tractable it may be to quantify the benefit.

Some benefits cut across all three classes of beneficiaries. The benefits/costs are organized in these three classes in order to provide a framework for understanding how priorities may be assigned to estimating each benefit/cost. Whether a market might emerge to facilitate compensation is also considered. Finally, the beneficiary sections suggest ways in which each benefit might be estimated. About 50 models are introduced that could be used to quantify the value of the set of 17 benefits or of a feasible subset. The TSI framework is used to outline the major effects of substituting DER for central station power plants, to evaluate whether markets are likely to capture the value of these effects, and to explain how challenging it will be to calculate a value of these effects.

Table 1 shows a summary of the effects that are described in this report. A symbolic scheme to summarize three important characteristics of each benefit is shown: economic magnitude, market likelihood, and ease of quantification (or tractability). The main purpose of this table is to offer an abbreviated comparison of the individual benefits/costs found in this study, with more detailed discussion to follow in Section 3. The three elements are explained below the table.

Table 1. Summary of DER Effects

	Benefits and Costs	Economic Magnitude	Market Likelihood	Analytic Tractability
1	Lower Cost of Electricity	$$, $$$	***	###
2	Consumer Electricity Price Protection	$, $$	***	##
3	Reliability & Power Quality[4] (RPQ)	$$ $, $$	*** *	## #
4	Combined Heat and Power/ Efficiency Improvement	$$$	***	###
5	Indoor Emissions	-$	*	##
6	Noise Disturbance	- $	*	##
7	Consumer Control	$	***	#
8	Electricity T & D Deferral and Congestion Relief	$$$	**	##
9	Capacity Deferral and Increase in Stranded Assets	+/-$$	*	##
10	Reduced Transmission Losses	$	*	##
11	Voltage Support to Electric Grid	$, $$	*	#
12	Reduced Security Risk to Grid	$$	*	#
13	Enhanced Electricity Price Elasticity	$, $$	*	#
14	Airborne or Outdoor Emissions[5]	+/- $$	*	##
15	DER Fuel Delivery Challenges	-$, -$$	**	##
16	NIMBY Opposition to New Central Power Plants & Transmission Lines	$	*	#
17	Land Use Effects	$	*	##

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[4] This benefit has two different aspects and two sets of rankings. The first is for RPQ benefit to DER owner. The second is RPQ benefit to utility and regional customers. Note that the benefits to the wider power system are highly uncertain both because the direct benefits are not easily known and because there may be highly uncertain secondary benefits, such as enhanced ability of the economy to tolerate low quality grid power. These are explained in section 3.1.3.

[5] This effect may be a benefit or a cost, therefore +/- is used to describe the economic magnitude.

1. Economic Magnitude: The relative size of the benefit or cost is indicated in this column. Costs are negative and benefits are positive. A number of benefits and costs have more than one value for economic magnitude, as a result of uncertainty and differences among applications.
    +/- $ = Small
    +/- $$ = Medium
    +/- $$$ = Large

2. Market Likelihood: This dimension tries to capture the possibility of markets developing that internalize the benefit or the cost. Effects that are not internalized represent a market imperfection and an opportunity for public or private entities to provide incentives for purchasers to adopt more DER.

    * = Market unlikely. Significant potential for direct policy intervention to change incentives.
    ** = Unclear market likelihood.
    *** = Market likely. Private benefit, value is internalized.

3. Analytic Tractability Scale: This measure refers to the possibility and ease of quantifying the benefit or cost, considering method, model, and data availability.

    # = Difficult to estimate.
    ## = Somewhat challenging to estimate.
    ### = Easy to estimate.

3. Effects of Distributed Energy Resources Deployment

Electricity generation from DER has substantially different effects than those associated with the conventional central power plant system. A conventional central power plant with a transmission and distribution network serves a large number of loads while DER serves only one or a relatively small number of loads through a local distribution system. Seventeen of the effects of DER electricity generation replacing central plants are described in this section. For the purpose of this report, these effects will be thought of in the context of meeting the 40 GW DEER goal by 2020.

Each effect is presented in a table with seven elements: Definition, Description, Economic Magnitude, Market Likelihood, Analytic Tractability, Methods or Models that can be used to quantify, and References. The definition and description explain the effect. The method chosen to evaluate the DER benefits was to evaluate each effect by three parameters. The three parameters are economic magnitude, market likelihood, and tractability. The methods and models sections suggest at least a starting point for trying to quantify each effect. The models referred to in this section are explained in more detail in the Appendix. The last element in each table is References, containing a resource list of sources that discuss either at length or in passing each particular effect.

3.1 Individual Adopters

In general, these effects are felt by the consumer directly and are most likely to be internalized. These are likely to be the most important drivers in a DER adopter's decision-making process, absent policy initiatives that provide incentives.

1. Lower Cost of Electricity
2. Consumer Electricity Price Protection
3. Reliability & Power Quality
    a. Sensitive load protection and power quality, and
    b. Avoiding outage costs.
4. Combined Heat and Power
5. Indoor Emissions
    a. Carbon monoxide,
    b. Volatile organic compounds,
    c. Waste lubricants/other materials, and
    d. Other toxics.
6. Noise Disturbance
7. Consumer Control

3.1.1 Lower Cost of Electricity

Definition:
The cost of buying electricity from the grid may be higher than the cost of installing and operating a DER unit onsite.

Description:
This benefit represents the difference between the cost of purchasing electricity and the cost of generating electricity onsite. Each case will yield a different cost or benefit that depends on the price of electricity charged by the utility to a specific customer, the load profile of the customer, the price of the DER unit, and other costs such as fuel, operations and maintenance, etc. This benefit accrues directly to the customer or to a developer acting on his/her behalf under a split savings arrangement. This benefit is likely to be the biggest driver in increasing DER adoption.

Economic Magnitude:
Most customers will install DER primarily based on this consideration. This benefit is straightforward and if the estimated payback is short, there may be rapid and significant market penetration.

Market Likelihood:
This effect is purely monetary and can be easily evaluated. An active DER market already exists, and will likely expand.

Analytic Tractability:
This effect should be easy to quantify because the data pertaining to electricity price (monthly bills) and commercial DER equipment is readily available. Predicting cost information for nascent technologies creates more uncertainty.

Methods/Models that can be used to Quantify:
A number of models are available off-the-shelf that can analyze the energy loads and electricity prices. These models include:

- Building Energy Analyzer: Estimates annual or monthly loads and costs associated with air-conditioning, heating, power generation, thermal storage and cogeneration systems for a given building and location.
- The Virtual Environment (VE): Among various other capabilities, it can be used to calculate energy consumption and costs.
- ADEPT: Helps optimize the performance and minimize the operating costs associated with electric and gas-powered cooling systems.
- Product Designer: Used to design products that hedge against volatile market prices and quantify impacts on customers' bills.
- DIStributed Power Economic Rationale SElection (DISPERSE): Assigns electric and thermal load profiles specific to the application and region, and the size of facility is used to "scale" the load profile. Combining this information with DER unit price and performance data, the model performs a life-cycle cost economic analysis, based on the unit life, the cost and performance data, and fuel prices. Baseload electric, cogeneration, and peak shaving operation modes are compared with competing energy prices. The best DER technology option is selected based on the lowest DER competing electricity price. The model then compares the annual cost to generate with costs of purchasing from the grid, and adds the application to the potential

market if it beats the grid price.

- D-Gen Pro: Evaluates the cost-effective application of on-site and distributed power generation.
- State-of-the-Art Power Plant (SOAPP): Helps evaluate the costs and benefits of distributed generation opportunities, solving for return on equity (including IRR and payback period) or for bus bar electricity costs.
- DER-CAM: Looks at on-site electricity and heat requirements and develop an optimal plan for customers to meet this requirement at overall minimum cost over a test period.

References:
(Cardell et al. 1998; Coles and Beck 2001; Robertson 2001; Shelor 1998; Swanekamp 1997)

3.1.2 Consumer Electricity Price Protection

Definition:
DER owners have a stronger ability to lock in prices for their energy requirements for the long term than customers directly exposed to volatile electricity prices. Additionally, in the short-run, consumers with real-time meters may switch between self-generation and buying power from the grid.

Description:
Price spikes occur primarily because of supply scarcity or a congested transmission network. There may also be times when generators exercise market power to drive up prices. Since the cost of electricity from the DER unit can be locked in by setting up a fixed long-term fuel contract more easily than electricity prices can be fixed, the customer can limit exposure to price volatility. This benefit is mostly a private benefit to the individual installing a DER unit.

Economic Magnitude:
The magnitude of this effect can vary between small and medium depending on price volatility (i.e. on the size of price spikes, the frequency at which those price spikes occur and their duration), and also on the risk preference of customers.

Market Likelihood:
A market exists for protection from price increases, but not yet for protection from real-time pricing and price volatility. This effect is purely monetary and given statistical parameters of price volatility, it can be taken into account while assessing the cost-effectiveness of installing a DER unit, by applying risk evaluation techniques. However, the likelihood and severity of price volatility in the emerging electricity markets is not yet well known, and perhaps more importantly, tariff reform that would expose customers to volatile rates will only emerge slowly, if at all.

Analytic Tractability:
This effect can be quantified given price volatility information.

Methods/Models that can be used to Quantify:
If the consumer "sees" the variation in the electricity price, i.e. has a real-time meter installed and buys electricity under an appropriate real-time tariff, the benefit of avoiding price volatility can be evaluated using standard risk evaluation methods.

References:
(Cardell et al. 1998; Coles and Beck 2001; Robertson 2001; Shelor 1998; Swanekamp 1997)

3.1.3 Reliability & Power Quality (RPQ)

Definition:
Reliability is typically defined as expected outage hours over a period, while power quality is loosely applied to various characteristics of electricity supplied (together RPQ), e.g. the occurrence and duration of voltage sags. DER can deliver RPQ benefits in two distinct ways. First, DER can deliver high quality power directly to sensitive end uses that require *gourmet* power. Second, the provision of sensitive loads locally by DER can increase overall tolerance of low RPQ on the grid. In other words, costs can potentially be lowered because the wider power system does not have to be tailored to sensitive loads. End-use RPQ requirements are highly heterogeneous, and DER enables provision of heterogeneous RPQ.

Description:
Many end-users will consider distributed generation for only one reason, to avoid outages and costs associated with power loss. Businesses that rely on their computer or telecommunication electronics being constantly powered want uninterrupted power supply. DER offers consumers choices among multiple levels of service quality. Benefits of DER to grid reliability are of two types. First, by lowering electricity throughput on the grid, and particularly by displacing on peak cooling load by absorption cooling grid requirements are reduced and reliability enhanced. This effect is particularly important because of growing electricity usage. Second, because DER allows utility consumers to customize their energy supply to their perceived needs, it may well also allow utilities to reduce costs by tolerating a lower level of overall grid reliability. DER in a sense partially takes responsibility for reliability away from the grid and places it in the hands of the customer. This frees the grid to establish levels of RPQ befitting its goal of serving non-sensitive loads most effectively. This added flexibility could deliver cost savings to the power system.

Economic Magnitude:
This is a large benefit to customers with specialized needs for high quality power and/or avoiding outages. The secondary benefit, to utilities from lower grid reliability, is also potentially significant, but is more uncertain.

Market Likelihood:
The likelihood that markets will allow DER owners to capture their internal benefits from higher RPQ is high. The chances of markets ensuring that DER adopters are compensated for their reduction in grid RPQ requirements and its associated cost savings are low.

Analytic Tractability:
Certain aspects of reliability can be quantified, e.g. some outage costs, but it would be difficult to estimate all elements of the consumer RPQ benefit, and finding preferable levels of power system reliability would be seriously intractable.

Methods/Models that can be used to Quantify:
Instruments that can monitor power supply are readily available in the market. With these instruments, the number and length of outages and lapses in power quality can be recorded. These costs of RPQ lapses could be estimated in various ways: lost production, corruption of data, and lost customers. No readily available methods could be used to assess the benefit of easing the power system of its RPQ obligation.

Models that can be used to assess reliability and power quality include:

- PQSoft: Produces and stores indices and statistics from power quality monitors. Evaluates the economics of power quality problems along with potential solutions. Analysis and forecasting of voltage sags.
- RAMELEC: Computes the frequency and magnitude of capacity shortages that might be expected in an area given assumptions about supply and demand. Using Monte Carlo simulation, the model determines the outages of generating units for each hour in the study. The difference between the demand forecast and the supply forecast for each simulation provides the probabilistic estimate of supply shortages.

References:
(Adams 2001; Ball et al. 1997; Blazewicz and Walker 2000; Brint et al. 1998; Brown and Freeman 2001; Burke; Cardell et al. 1998; Chowdhury 1999; Cowart 2001; Donnelly et al. 1996; Feibus 1999; Gates 1999; Hadjsaid et al. 1999; Hennagir 1997; Hirst and Kirby 1997a; McDermott; Osborn and Kawann 2001; Taylor, Carson W. 1999; Taylor, Tim; Wang and Billinton; Warren 1999)

3.1.4 Combined Heat and Power

Definition:
Combined Heat and Power (CHP) is the recovery of electricity generation waste heat to meet heating or cooling needs thereby reducing the fuel needed to heat or cool. The application of CHP potentially provides an opportunity to significantly increase the overall efficiency of energy use, with all the attendant benefits, e.g. lower carbon emissions.

Description:
CHP is arguably the most important benefit when it comes to advancing the market penetration of DER. As an example, the heat produced from a reciprocating engine at an office building can be used for space heating, heating water, or for absorption chillers. This office building can save money by reducing the need for additional fuels to deliver these heating or cooling services. Therefore, the total energy (not just electricity) efficiency of the DER system can be improved substantially. This benefit can be directly captured by the site. The external benefits that result from lower energy use may not be. Note particularly the connection between CHP, energy efficiency, and GHG emissions discussed in 3.3.2.

Economic Magnitude:
The benefit from CHP is primarily a private benefit. CHP has large economic benefits

and these benefits alone are the sole reason for many installations. CHP can lead to efficiencies of 70 to 95 percent (U.S. Combined Heat and Power Association 2002), while typical single-cycle efficiencies are 30-50 percent. These benefits are very manageable to estimate.

Market Likelihood:
There is already a market. This direct effect of lower fuel use can be internalized easily, but not the external benefits.

Analytic Tractability:
This internal benefit can be quantified easily, by analyzing the size of the owner's heating/cooling loads and then determining how much of this load is replaced by CHP unit.

Methods/Models that can be used to Quantify:
HEATMAP: Designs and evaluates district energy systems, including combined heat and power (cogeneration).
RECIPRO: Selects and optimizes cogeneration systems for hotels, hospitals, institutional buildings and small industrial applications.
Cogeneration Ready Reckoner: Does preliminary analysis of the technical and economic potential of cogeneration projects.
D-Gen Pro: Evaluate the cost-effective application of on-site and distributed power generation.
DER-CAM: Optimizes customer adoption, it has been developed that looks at on-site electricity and heat requirements and develops an optimal plan for customers to meet this requirement at overall minimum cost over a test period.
DIStributed Power Economic Rationale SElection (DISPERSE): Assigns electric and thermal load profiles specific to the application and region, and the size of facility is used to "scale" the load profile. Combining this information with DER unit price and performance data, the model performs a life-cycle cost economic analysis, based on the unit life, the cost and performance data, and fuel prices. Baseload electric, cogeneration, and peak shaving operation modes are compared with competing energy prices. The best DER technology option is selected based on the lowest DER competing electricity price. The model then compares the annual cost to generate with costs of purchasing from the grid, and adds the application to the potential market if it beats the grid price.
Clean Energy Technology Economic and Emissions Model (CETEEM): CETEEM was developed to analyze the dynamics of DER and CHP system operation with varying building electrical load profiles, including estimating system performance /efficiency, economics, and lifecycle emissions of criteria pollutants and GHGs.

References:
(CADDET 1999; CADER 1999; Elsobki and El-Salmawy 2001; Harrison 2001; International Energy Agency 1983; Marnay et al. 2001; Onsite Sycom Energy 2000; Rubio et al. 2001; U.S. Combined Heat and Power Association 2002)

3.1.5 Indoor Emissions

Definition:
The physical proximity of DER units to people may create health risks due to indoor

emissions from the DER unit.
Description: DER units are usually situated very close to their load and consequently are close to people. DER waste such as oil, solid waste, or airborne emissions of carbon monoxide, volatile organic compounds, and particulate matter, may hurt people or property. For example, a leak in the exhaust system of a reciprocating engine can lead to carbon monoxide (a hazardous colorless and odorless gas) being released inside an office building. Here we consider emissions that are released to the atmosphere but re-enter buildings to be part of airborne or outdoor emissions.
Economic Magnitude: The different DER technologies have different emissions and potentials for indoor exposure. The magnitude of this effect is described as modest because only a fraction of units will be mishandled or malfunction. Additionally, many exposures would not be severe exposures.
Market Likelihood: The cost of indoor emissions is a private cost in the sense that indoor emissions affect the same institution that invests in the DER. The costs are substantially internalized. However, there are also issues of occupational safety to consider, and those exposed to the emissions within or near an installation will probably not be the actual DER investors.
Analytic Tractability: This effect can be observed by installing monitoring instruments that measure the air quality and note any malfunctions in the system. This cost, however, is site specific and it would be a very difficult task to evaluate it nationally.
Methods/Models that can be used to Quantify: HEATMAP: Studies long-term environmental impacts of existing and proposed systems. Key program features include the capability to analyze air-pollutant emissions, including carbon dioxide, from existing energy sources; compare those levels with air quality that would result after implementation of district energy systems; and determine the effect of environmental taxes. Local Scale Modeling of Human Exposure Microenvironments: Models local-scale meteorological and air dispersion that provides ambient air concentrations resulting from transport and other human activities. It can establish the direct relationships between source-to-exposure concentrations specific to the particular exposure microenvironment.
References: (Bluestein 2000; California Air Resources Board 2000; Greene and Hammerschlag 2000; Hoskins 1998; Iannucci et al. 2000; Ishii 2001; Koshland et al. 1999; Krebs 2001; Lents and Allison 2000; Meyers and Hu 2001; Regulatory Assistance Project 2001; SanMartin 1989)

3.1.6 Noise Disturbance

Definition: Electricity generation can be noisy. The proximity of a DER unit to people makes this a potential disbenefit. In some cases, noise irritation will be a deal breaker for DER projects.

Description: A micro-turbine produces noise at about 70 dB (at 10 m), while natural gas and diesel reciprocating engines make between 70 and 90 dB (at 7 m) of noise. DER noise may well affect the customers of a business, lower the productivity of employees, and irritate neighbors. Occupational health requirements and local noise ordinances will limit deployment of DER technologies.
Economic Magnitude: While the total cost of noise nuisance is large, the economic potential of this cost is intermediate because noise can be attenuated and there are quiet DER options. However, in some situations noise will be enough to keep a customer from adopting DER.
Market Likelihood: A market is unlikely to develop because the noise disbenefit is both a private and external cost. This effect is very hard to internalize. Compliance with noise ordinances is probably the only requirement.
Analytic Tractability: Measuring noise damage is somewhat difficult because noise damage is highly dependent on local circumstances, and the effect is at least in part a subjective quality of life issue.
Methods/Models that can be used to Quantify: One method that could estimate the value of this cost, is an economic survey technique, the contingent valuation or "willingness to pay" method. Much of the literature on traffic noise that applies these methods suggests approaches to this problem.
References: (Cummins Onan Power Generation 2000; Katolight Power Systems 2000; Makelim Power Systems (Kohler Generators) 2000; Schunck and Lisiecki 1998)

3.1.7 Consumer Control

Definition: Because the electricity grid is a large centrally controlled system, it seems beyond the influence of an individual customer and may offend a customer's sense of individualism and independence. The "control" that DER offers therefore can be appealing and will benefit many with an individualistic outlook.
Description: Some people like to be "in control" or "in charge" of all facets of their life and may abhor the whole interaction with a centralized utility. In other cases, people may want to ensure that their power is generated in an environmentally friendly manner. These consumers may opt for a DER technology that fits with their values.
Economic Magnitude: There is no easy way to estimate the scale of this benefit. It is rated as small in Table 1.
Market Likelihood: There is a market for self-control. The market will provide independence to those who seek it. This is a private benefit and people who prefer their own power will install DER and those who do not, will not.
Analytic Tractability: This effect can be very hard to quantify since it is subjective and usually has no formal

assessment associated with it. Economists have used contingent valuation studies to show the existence of deontological ethics, (i.e. that value is placed by an individual on a decision based on personal feeling of “what is right”). However, the ability to quantify the value of an ethical benefit such as “Its better for the earth if DER replaces central plants” is rather limited. (Soderholm and Sundqvist 2000)

Methods/Models that can be used to Quantify:
The cost of a DER technology (the basic cost of equipment, fuel, operations and maintenance) as provided by vendors and other market suppliers could be compared to the price that the customer is willing to pay for independence.

References:
(Soderholm and Sundqvist 2000)

3.2 Utilities

The effects that can accrue to utilities include:

1. Electricity T & D Deferral and Congestion Relief
2. Capacity Deferral and Increase in Stranded Assets
3. Reduced Transmission Losses
4. Voltage Support to Electric Grid
5. Reduced Security Risk to Grid
6. Increase in Stranded Assets

Utility specific benefits are private benefits, but insofar as utility savings should lead to lower costs that will accrue in part to ratepayers and in part to shareholders, all of the utility benefits are a mix of private and public benefit.

3.2.1 Electricity T & D Deferral, and Congestion Relief

Definition:
The benefit of avoiding new power sector capital investments and the related risks necessary to meet growing load.

Description:
Planning of expansion or upgrade of the transmission and distribution network is based on projections of increase in demand and needs for equipment replacement. If self-generation defers the need for this investment, savings will accrue to the transmission and distribution company.

Consumers located in remote regions where extending the transmission line would entail a large investment relative to revenues could be more efficiently served by DER. Remote terrain may also lead to difficulties in maintaining the extended transmission line. In such cases the utility may benefit from installing an onsite generator to avoid the investment in the transmission line.

Economic Magnitude:
Given the magnitude of the increase in demand over the planning horizon including its spatial expansion, this benefit could be substantial.

Market Likelihood:
Deferring the expansion and upgrading of the T & D system, benefits the public. T & D systems are regulated and pass their costs on to its customers. The market is unlikely to compensate the DER investor for this benefit. While it is possible to imagine compensation schemes to internalize this benefit by subsidizing DER investments, these are unlikely in practice.

Analytic Tractability:
Estimating the value of the deferral benefit to a utility should not be too hard. Electric utility planning tools can be used to assess the trade-offs between deploying small DER units and building new or upgrading existing T&D networks. Estimating the public benefit of deferral is a little harder.

Methods/Models that can be used to Quantify:
UPLAN-NPM (Network Power Model): Forecasts market price, asset valuation, resource planning and AC/DC load flow.
Financial Analysis Tool for Electric Energy Projects (FATE2-P): Calculates Cost of Energy or Internal Rate of Return for alternative energy projects. This is a power plant project finance model.
Remote Power Applications Model (RPAM): Simulates specified remote power system and line extension, and then performs a standard utility revenue requirement calculation to evaluate the economics. The model calculates the stream of revenue requirements to support the capital investments, O&M and other annual payments. The line extension model uses the standard engineering limits of voltage drop and maximum capacity to size the line appropriately. The line extension and remote power system are compared on the basis of the life cycle cost of their two revenue streams.
GE MAPS: Models transmission topology and the distribution of loads to help predict the dispatch of generation throughout the system. GE-MAPS software can evaluate: spot prices or locational marginal prices (LMP), shadow prices, determination and evaluation of transmission congestion, environmental compliance strategy analysis, siting of new generation, evaluation of assets, and determination of projected revenue streams.

References:
(Ault et al. 2002; Ball et al. 1997; Barsali et al. 2001; Carvalho and Ferreira; Cavanagh and Sonstelie 1998; Chow et al. 1998; Comnes et al. 1995; Electric Power Research Institute 1999; Hadjsaid et al. 1999; Hirsch and Serchuk 1999; Knapp et al. 2000; Willis 1997)

3.2.2 Capacity Deferral and Increase in Stranded Assets

Definition:
If increasing numbers of customers adopt DER, the demand for centralized generation capacity would likely decrease. In the short term, pre-existing capacity investments may not be recoverable and could result in a “stranded” cost. In the longer term, further expansion of DER would prevent the new construction of central station capacity. The accompanying benefit is less capital tied up in building new centralized generation with more invested in DER.

Description:
Generation capacity is largely privately financed. Investors plan to build new generation

capacity based on demand projections. Within the next 20 years, almost 374 GW of new capacity additions are forecasted to meet the projected demand, according to AEO2002. Under the traditional regulated energy market when most of the demand was met through centralized conventional power plants, planners estimated some probability of the demand not materializing. This uncertainty would likely increase in the short term due to a large shift toward DER adoption. If the demand in central station generation is lower than projected due to increased DER, the investment made in this central generation capacity could become stranded. Such investments could lead to increased risk associated with future upkeep requirements, resulting in a “disbenefit” to society. In the longer term, power plant companies could forego future investments in central stations and meet growing demand by investing in DER units that can be installed with shorter lead times and closer to the new load centers. This could reduce the potential investment risks associated with stranded assets with less invested in central station capacity. This would be a more efficient allocation of financial resources and consequently a benefit to the society.

Economic Magnitude:
The financial resources necessary to build a conventional power plant are very large. However, if the financial resources are allocated more efficiently through smaller investments there could be a benefit. The magnitude of this benefit may not be as large as the stranded costs associated with a conventional power plant.

Market Likelihood:
The cost due to stranded investments or the benefits of deferring the building of new capacity directly benefits the power plant company. It is unlikely that these effects would affect the DER investor.

Analytic Tractability:
Estimating the value of the cost due to stranded investments or the benefits due to capacity deferral should not be too hard. Electricity generation capacity planning tools can be used to assess the trade-offs between deploying small DER units and building new conventional central power plants. Estimating the public benefit of more efficient allocation of financial resources is a little harder.

Methods/Models that can be used to Quantify:
UPLAN-NPM (Network Power Model): Forecasts market price, asset valuation, resource planning and AC/DC load flow.
Financial Analysis Tool for Electric Energy Projects (FATE2-P): Calculates Cost of Energy or Internal Rate of Return for alternative energy projects. This is a power plant project finance model.
Cost of Service Model (COSMO): Computes the area-specific marginal costs resulting from being able to defer, or from having to accelerate, the construction of capacity units due to a change in the capacity requirements.
Area Investment Models (AIM): Balance capacity investment costs with the potential cost of unserved energy under load growth uncertainty and various reliability criteria.

References:
(Ault et al. 2002; Ball et al. 1997; Barsali et al. 2001; Carvalho and Ferreira; Cavanagh and Sonstelie 1998; Chow et al. 1998; Comnes et al. 1995; EPRI 1999; Hadjsaid et al. 1999; Hirsch and Serchuk 1999; Knapp et al. 2000; Willis 1997)

3.2.3 Reduced Transmission Losses

Definition: Electricity is lost when it is transmitted through wires from a central generating station to the customer. The larger the distance over which it is transmitted the more the losses are, and losses also increase with current and so are higher for heavily loaded lines. Siting small-scale generation close to load lowers losses.
Description: Power losses that occur while transmitting power over transmission lines are directly proportional to the distance over which the power is transmitted at constant current. In the U.S. about 7 percent of the total power transmitted is lost. Deploying smaller DER units close to the load center would avoid such power losses. To avoid losses, it is preferable to build conventional central power plants close to the loads. DER by definition is close to loads and incurs lower losses. Additionally, loss increases with current so lowering line loading overall also saves energy.
Economic Magnitude: Lowering losses could be a modest benefit.
Market Likelihood: Usually, the utility passes the costs of transmission losses on to their customers through prices. The benefit from reducing transmission losses accrues to the DER owner to the extent that on-site generated power will be cheaper relative to purchased power. Losses within the site can be substantial and are also reduced. General loss reduction in the wider power system accrues to T&D owners and is unlikely to be captured by DER owners.
Analytic Tractability: While overall losses in the power system are readily estimated as the gap between total generation measured at the power plant bus bar and total sales measured at the customer meter, estimating the benefit from a net change to the system, such as by the addition of an individual DER installation is complex, if not impossible. This difficulty arises because the only method of estimating the delta in losses is by a power flow calculation. Conducting a calculation is data intensive and is only valid for a certain pattern of loads and generation. Through time these patterns change constantly, so a complex study would be necessary to measure the total effect.
Methods/Models that can be used to Quantify: Electric utility planning tools can be used to assess the trade-offs between deploying small DER units and transmission line losses created through long distance transmission of electricity to supply the same load. Power flow models can estimate losses under certain conditions.
References: (Energy Information Administration 2001)

3.2.4 Voltage Support to Electric Grid

Definition: Small-scale generation in the distribution system can support voltage by injecting reactive power thereby improving power quality and lowering losses.
Description: The ability of DER to provide system ancillary services is limited by the low voltages and sizes of DER units, but nevertheless, DER may be able to provide some localized benefits, such as voltage support. By providing reactive power to the local distribution system, DER could raise voltages to customers nearby, thereby improving the quality of their service and reducing distribution system losses. However, the potential of DER to provide this service is limited by the voltage step up and their small size.
Economic Magnitude: Voltage support is a small to medium-sized benefit. While the potential of DER to deliver the service is limited, losses in distribution are significant, much larger than in high voltage grids.
Market Likelihood: This is a benefit DER will only provide if compensated. Markets are unlikely to emerge to internalize the benefit because of the localized nature of the problem. It is unlikely that utilities would want to compensate DER owners for providing such a service because other alternatives such as installing capacitors have lower transaction costs.
Analytic Tractability: Quite hard because of localized nature. Power flow models can estimate losses and benefits of VAR injection, but power flows are only valid for a limited range of conditions.
Methods/Models that can be used to Quantify: Windmil: Analyzes a system by feeder, substation, or the entire system. (Marnay et al. 2000)
References: (Didden et al.; Didden et al. 2002; Gomez, J.C. and Morcos; Gomez, Tomas et al. 1999; Hirst and Kirby 1996; Hirst and Kirby 1997a; Hirst and Kirby 1997b; Hirst and Kirby 1998; Malins 1998; Marnay et al. 2000)

3.2.5 Reduced Security Risk to Grid

Definition: More DER units will reduce the reliance on the central grid, making the grid a less appealing terrorist target and will reduce the impact of other grid disruptions.
Description: A conventional central power plant with a T&D network supplies electricity to a large number of consumers. Further, the system is brittle so the loss of individual facilities can bring the whole system down; therefore, central power plants and transmission lines are excellent terrorist targets. The task of securing assets would be impossible both because

of the numerous locations of the central power plants, substations, etc., and because the routes of transmission pass over remote terrain. Having DER supply critical loads instead of a fully centralized system creates a more robust system thereby making the grid a less attractive target.
Economic Magnitude: The benefit of the reduced security risk to the electricity grid is an important private and public benefit. Estimating the magnitude of this benefit is challenging because the risks are small, but the potential loss is tremendous.
Market Likelihood: This benefit would be very difficult to internalize through markets. The public benefit is widespread and can be quite intangible.
Analytic Tractability: Estimating the value of this benefit is difficult because current risk and reduced risk are difficult to establish.
Methods/Models that can be used to Quantify: One potential method to quantify this benefit would be to survey insurance carriers to determine how they would calculate the risk premium and value grid reliability.
References: (Curcic and Creighton 2001; Eto et al. 2001; Hadley and Van Dyke 2002)

3.3 Regions (Local, National, and Global)

There are several effects of DER adoption that would accrue to society as a whole. These benefits generally have the most potential for policy intervention.

In this section we describe the benefits that can accrue at different spatial levels. The categories under which these effects fall are:

1. Enhanced Electricity Price Elasticity
2. Airborne or Outdoor Emissions (NO_X, SO_2, Hg, toxics, PM, Greenhouse gases)
3. DER Fuel Delivery Challenges
4. NIMBY
5. Land Use Effects

3.3.1 Enhanced Electricity Price Elasticity

Definition: DER increases electricity demand elasticity, which will tend to lower prices to the benefit of all consumers.
Description: Currently, electricity customers do not have many ways to respond to changing electricity prices. Few customers have the flexibility or the means to alter their behavior according to the changing electricity prices, but DER changes this picture significantly. Having the option of using an onsite DER unit to generate electricity instead of buying from the grid, gives the DER customer the ability to “respond” to prices. In other words, the elasticity of demand for electricity from the grid increases when more and more customers install DER units. Enhanced demand elasticity can lower prices and curb the exertion of market power by generators. This creates a societal benefit captured by all electricity consumers.

The ability of DER owners to respond to prices will vary considerably depending on circumstances. For example, having to meet on-site CHP requirements will lower operating flexibility.
Economic Magnitude: The magnitude of this effect can be large. The larger the ratio of DER adopters to the total customer base, the more elastic market electricity demand would potentially be. However, the ability of DER owners to respond to prices will be highly variable.
Market Likelihood: It is unlikely any market mechanism will emerge whereby the gainers, i.e. electricity consumers, generally will compensate DER owners.
Analytic Tractability: Estimation of demand elasticity is a notoriously difficult task and quantifying this effect would be difficult. However, analysis of market offer and bid curves could yield estimates of the benefit.
Methods/Models that can be used to Quantify: Analysis of market outcomes and behavior and/or simulation and auction experiments could be used to estimate potential gain.
References: (Cardell et al. 1998; Coles and Beck 2001; Robertson 2001; Shelor 1998; Swanekamp 1997)

3.3.2 Airborne or Outdoor Emissions (NO_x, SO_2, Hg, Toxics, PM, and GHG's)

Definition: Fuel based electricity generation leads to emissions of many byproducts. The pattern of emissions from outdoor or airborne pollutants such as NO_x, SO_2, and others from DER units would be different and potentially less hazardous then emissions of the conventional plants that DER replaces.
Description: Emission rates and heat rates (or efficiency) of DER technologies are different than the technologies of conventional central power plants. Depending on which conventional central plant is displaced by which DER technology, the emissions of different pollutants can either increase or decrease. Even if central station and DER emissions were similar, the differences in location and the concentration of emissions would lead to different emission effects. In some cases, DER would lead to emissions increases because dirtier DER units replace cleaner conventional plants and vice-versa. Perhaps more importantly, the location of emissions might change detrimentally. Emitting a similar mass of pollutant at ground level in a densely populated area could result in more human exposure than a similar mass emitted from a high stack and/or at a remote location. Change in emissions has both a direct and an indirect effect on human health and the environment. For example, NO_x emissions directly affect human health when inhaled. NO_x can also act as a precursor to ground-level ozone or particulate matter and indirectly affect human health. In other words there are multiple pathways in which the emissions of these pollutants can affect human beings.

Fuel cells have lower emission rates for NO_x, SO_2, toxics, PM, and GHGs than a conventional natural gas combined cycle plant that does not have any post-combustion controls installed on it. However, natural gas fired combined cycle (NGCC) plants are highly efficient and have low emission rates as compared to uncontrolled micro-turbines. So if an NGCC plant is displaced by the micro-turbines, emissions may increase.
Economic Magnitude: Reduced or increased emissions are an important public benefit/cost. However, monetizing the value of harming or protecting public health is a contentious subject. Due to the uncertainty regarding which DER units would replace which central plants, this effect cannot be definitively called a benefit or a cost. Because we tend to value human health so highly, this effect tends to dominate environmental externality estimates.
Market Likelihood: Unlikely. Currently, there are several market-based programs for reducing NO_x and SO_2 emissions from conventional central power plants. For example, there is a regional cap-and-trade program for reducing NO_x emissions in the northeastern U.S. There are also international carbon trading markets emerging, as permitted under the Kyoto Protocol. However, the transaction cost of extending such a program to DER where the number of sources that would have to be monitored is extremely large may be too high. There are a few ideas/proposals that suggest that DER could be treated as mobile sources with emission standards imposed on the lines of the tailpipe emission standards.
Analytic Tractability: This benefit is very difficult to quantify reliably, because of the uncertainty associated with geography, which technologies will be replaced, and the value of human health. However, putting a value on this benefit or disbenefit could be done after making quite a few assumptions in regards to weather, exposure, and the value of health and saving a life. The national policy models could help quantify national emissions from a particular capacity mix. The local and regional air pollution models coupled with health risk models could help estimate the mortality and morbidity effects.
Methods/Models that can be used to Quantify: The national policy models could help quantify national emissions. Urban Airshed Model (UAM): Simulates regional transport of pollutants and their physical/chemical transformations spatially and temporally. Tracking and Analysis Framework (TAF): Links together into an integrated framework the key acid deposition components of pollutant emissions; control costs; atmospheric transport and deposition; environmental effects on visibility, lakes, soils, and human health; and valuation of these effects.
References: (Amano 1998; Bluestein 2000; Burtraw et al. 1998; California Air Resources Board 2000; Casler and Rose 1998; Greene and Hammerschlag 2000; Hoskins 1998; Iannucci et al. 2000; Ishii 2001; Jacoby 1998; Knapp 1999; Koshland et al. 1999; Krebs 2001; Lents and Allison 2000; Mayerhofer et al. 1997; Meyers and Hu 2001; Price et al. 2002; Regulatory Assistance Project 2001; SanMartin 1989)

3.3.3 DER Fuel Delivery Challenges

Definition:

The number of typical DER units that might substitute for one conventional central power plant would be large. Hence, fuel delivery systems must be extended to bring fuel to the DER unit.

Description:
Fuel delivery systems would have to be maintained and their security and reliability would have to be ensured. A complex natural gas delivery system exists but it would need to be expanded, possibly dramatically.

A conventional 600 MW NGCC plant could be substituted by 6000 100 kW microturbines. However, then a transmission and distribution system to supply natural gas to each dispersed DER unit may have to be developed and maintained instead of one single pipeline to supply the NGCC plant.

There would be safety issues regarding this natural gas T&D system that could be more critical since these DER units may be located in buildings. Also, there may be a need to have fuel storage facilities to ensure an uninterrupted supply for DER units in case of fuel supply disruptions.

T&D systems exist for supplying natural gas in some regions. However, hydrogen gas, which powers fuel cells, does not yet have the associated infrastructure required for wider spread use. For hydrogen gas, a T&D network would have to be created from the ground up.

Economic Magnitude:
The economic scale of this effect could be moderate. This challenge of maintaining significant T&D networks for DER fuel is a widely socialized cost. The land required, the safety risk, and additional costs would be spread among many DER users and/or all fuel consumers.

Market Likelihood:
The burden of extending fuel supply infrastructure would fall on all fuel consumers and would not affect DER adopters beyond their own fuel cost burden.

Analytic Tractability:
It would be quite tractable to estimate the cost of expanding the current distribution system, but evaluating the costs of developing infrastructure for new fuels, notably hydrogen, is obviously much more problematic.

Methods/Models that can be used to Quantify:
UPLAN-G: Gas Procurement and Competitive Analysis System: Provides a detailed analysis of all aspects of gas planning including resource portfolio optimization, gas dispatch, pipeline sizing, facilities planning, and demand-side management.

References:
(Bernstein et al. 2002; Buonanno et al. 2001; Cavanagh and Sonstelie 1998; Environmental Systems Research Institute 1998; Lyon and Toman 1991; Meritet 1999; Scott 1998)

3.3.4 NIMBY Opposition to New Central Power Plants and Transmission Lines

Definition:

Opposition to small scale on site facilities is likely to be less of an impediment to development of DER than of central stations.

Description:
NIMBY, or “Not In MY Backyard”, is a common sentiment that people have regarding where to site new power plants. A cry goes up for new power plants whenever a power emergency hits, but once a site is chosen for a new power plant, opposition raises up from many directions. City councils, private citizens and other groups regularly oppose only new power plants, and not just new coal or nuclear plants. The problem is even more severe for transmission line projects, which usually succeed or fail based on local opposition. Investment in transmission has been falling in the U.S. since the 1980’s. Nobody wants the newest and cleanest plants or power lines near their homes or schools. This seeming contradiction, that while everybody wants more power, lower prices, and no blackouts, yet nobody wants the new power plants to be built nearby, is longstanding and intractable. More DER should reduce the number of central station plants built near people who share NIMBY sentiment.

Economic Magnitude:
Small overall, even NIMBY opposition to central station power can be a significant force.

Market Likelihood:
Overall benefit to expansion of the power system is unlikely to be internalized.

Analytic Tractability:
Difficult.

Models or Methodology for Quantification:
Perhaps indirectly by evaluating property value changes in areas where central plants were built and in areas where plants were not built.

References: NA

3.3.5 Land Use Effects

Definition:
Having the option of generating power onsite provides the “freedom” for consumers to locate their activities in any location of their choice and could encourage urban sprawl. Increasing urban sprawl can have adverse effects on the natural environment.

Description:
At present the location of transportation, power, and other municipal services exerts influence on an individual deciding on the location of a house or business. If the business is far away from the electricity T&D network, it might entail the additional cost of expanding that network. The DER option enables locating the business far away from the grid. Furthermore, it is likely that the value of property that is located close to existing infrastructure is higher than that of the property that is located in remote regions.

The “foot-print” of a human activity can be adverse to the natural environment. If more and more individuals choose remote locations for business or for living, more and more land would lose its pristine nature.

Economic Magnitude:
The size of this cost is purely speculative.

Market Likelihood: It is very unlikely this cost could be internalized.
Analytic Tractability: This cost would be difficult to estimate.
Methodology for Analysis/Evaluation/Quantification: There are not readily available methods other than willingness to pay studies of the value of open space, but many of these, e.g. on national parks, do exist.
References: NA

Bibliography

Adams, H. W., Jr. 2001. "Business Model for Reliability Management in Deregulated Markets." *Power Engineering Society Summer Meeting, 2001. IEEE,* (1): 576-577 vol.1.

Amano, A. 1998. "Climate Change, Response Timing, and Integrated Assessment Modeling." *Environmental Economics and Policy Studies*, 1 (1), 3-18.

Ault, G. W., C. E. T. Foote, and J. R. McDonald. 2002. "Distribution System Planning in Focus." *IEEE Power Engineering Review*, 22 (1), 60-62.

Ball, G., D. Lloyd-Zannetti, B. Horii, D. Birch, R. E. Ricks, and H. Lively. 1997. "Integrated Local Transmission and Distributed Planning Using Customer Outage Costs." *The Energy Journal*, DR Special Issue, 137-160.

Barsali, S., G. Celli, M. Ceraolo, R. Giglioli, P. Pelacchi, and F. Pilo. 2001. "Operating and Planning Issues of Distribution Grids Containing Diffuse Generation." *Electricity Distribution, 2001. Part 1: Contributions. CIRED. 16th International Conference and Exhibition on (IEEE Conf. Publ No. 482)*, (4): 5 pp. vol.4.

Bernstein, M. A., P. D. Holtberg, and D. Ortiz. 2002. "Implications and Policy Options of California 'S Reliance on Natural Gas." The Energy Foundation.

Blazewicz, S., and S. Walker. 2000. *Distributed Generation: What Will It Take to Deliver Grid Reliability?* Power Value, 12-15.

Bluestein, J. 2000. "Environmental Benefits of Distributed Generation." Energy and Environmental Analysis, Inc., (December).

Brint, A. T., W. R. Hodgkins, D. M. Rigler, and S. A. Smith. 1998. "Evaluating Strategies for Reliable Distribution." *IEEE Computer Applications in Power* (July), 43-47.

Brown, R. E., and L. A. A. Freeman. 2001. "Analyzing the Reliability Impact of Distributed Generation." *Power Engineering Society Summer Meeting, 2001. IEEE,* (2): 1013-1018.

Buonanno, S., W. Palenzona, G. Pasin, and G. Torsello. 2001. "Economic Assessment of the Installation of Natural Gas-Fuelled Microturbines and Results of Preliminary Tests." *Electricity Distribution, 2001. Part 1: Contributions. CIRED. 16th International Conference and Exhibition on (IEE Conf. Publ No. 482)*, (4): 4.

Burke, J.; "Determining the optimum level of reliability," Transmission and Distribution Conference and Exposition, 2001 IEEE/PES , Volume: 1, Page(s): 439 -443, 28 October-2 November 2001.

Burtraw, D., A. Krupnick, E. Mansur, D. Austin, and D. Farrell. 1998. "Costs and Benefits of Reducing Air Pollutants Related to Acid Rain." *Contemporary Economic Policy*, 16 (4), 379-400.

CADDET. 1999. *Efficient, Low-Emission Gas Turbine Chp Installation.*

CADER. 1999. "Chp Technologies." Sacramento.

California Air Resources Board. 2000. "Risk Reduction Plan to Reduce Particulate Matter Emissions from Diesel-Fueled Engines and Vehicles." California Air Resources Board, CA-ARB, Sacramento, CA. (October 2000). 38.

Cardell, J., M. Ilic, and R. D. Tabors. 1998. "Integrating Small Scale Distributed Generation into a Deregulated Market: Control Strategies and Price Feedback." Laboratory for Electromagnetic and Electronic Systems, M.I.T., Boston, MA. (April, 1998). 184.

Carvalho, P.M.S.; Ferreira, L.A.F.M.; "Robust expansion planning of distribution networks with independent generators," Transmission and Distribution Conference and Exposition, 2001 IEEE/PES , Volume: 1 , Page(s): 498 -503, 28 October-2 November 2001.

Casler, S. D., and A. Rose. 1998. "Carbon Dioxide Emissions in the U.S. Economy: A Structural Decomposition Analysis." *Environmental and Resource Economics*, 11 (3-4), 349-63.

Cavanagh, R., and R. Sonstelie. 1998. "Energy Distribution Monopolies: A Vision for the Next Century." *The Electricity Journal*, 11 (7), 13-23.

Chow, M.-y., J. Zhu, and H. Tram. 1998. "Application of Fuzzy Multi-Objective Decision-Making in Spatial Load Forecasting." *IEEE Transactions of Power Systems*, (13): 1185-1190.

Chowdhury, A. A. 1999. "Value-Based Power System Reliability Planning." *IEEE Transactions on Industry Applications*, 35 (2), 305-11.

Coles, L., and R. W. Beck. 2001. "Distributed Generation Can Provide an Appropriate Customer Price Response to Help Fix Wholesale Price Volatility." *Power Engineering Society Winter Meeting, 2001. IEEE*, (1): 141-143.

Comnes, G. A., S. Stoft, N. Greene, and L. J. Hill. 1995. "Performance-Based Ratemaking for Electric Utilities: Review of Plans and Analysis of Economic and Resource-Planning Issues." *LBL-37577. UC-1320*, Energy & Environmental Division. Lawrence Berkeley National Laboratory. University of California., Berkeley, California 94720. (November). 106.

Cowart, R. 2001. "Distributed Resources and Electric System Reliability." The Regulatory Assistance Project. (September 2001).

Cummins Onan Power Generation. 2000. *Manufacturer's Technical Specification Sheets for Diesel and Natural Gas Generators.*

Curcic, S., and A. Creighton. 2001. "Emerging Aspects of Risk Management within Distribution Businesses." *Electricity Distribution, 2001. Part 1: Contributions. CIRED. 16th International Conference and Exhibition on (IEE Conf. Publ No. 482),* (6): 6.

Didden, M., R. Belmans, and W. D'haeseleer. 2001. "Lessons Learned from a Thorough Voltage Sag Case Study." *PQA'2001 Conference*, Pittsburgh.

Didden, M., R. Belmans, and W. D'haeseleer. 2002. "Persuading Consumers to Invest in Voltage Sag Mitigation Devices." *EPRI-PQA'2002*, Portland.

Donnelly, M. K., J. E. Dagle, D. J. Trudnowski, and G. J. Rogers. 1996. "Impacts of the Distributed Utility on Transmission System Stability." *Power Systems, IEEE Transactions on*, 11 (2), 741-746.

Electric Power Research Institute. 1999. "Generic Analytical Models for Assessing Distribution System Design Implications of Distributed Generation and Storage." *TR-114156*, EPRI, Palo Alto. (December 1999).

Elsobki, M. S. J., and H. A. El-Salmawy. 2001. "An Integrated Resource Planning Formulation Using a Simultaneous Electric/Thermal Production System." *Electricity Distribution, 2001. Part 1: Contributions. CIRED. 16th International Conference and Exhibition on (IEE Conf. Publ No. 482),* (4): 5.

Energy Information Administration. 2001. "Annual Energy Outlook 2002." *DOE/EIA-0383(00),* U.S. Department of Energy, Washington, D.C., (December 2001). 255.

Environmental Systems Research Institute. 1998. *Geography Matters to Electric and Gas Utilities.* http://www.esri.com/industries/electric/electric.html

Eto, J., C. Marnay, C. Goldman, J. Kueck, B. Kirby, J. Dagle, F. Alvarado, T. Mount, S. Oren, and C. Martinez. 2001. "An R&D Agenda to Enhance Electricity System Reliability by Increasing Customer Participation in Emerging Competitive Markets." *Power Engineering Society Winter Meeting, 2001. IEEE,* (1): 247-251 vol.1.

Feibus, H. 1999. "The Role of Distributed Generation in a Restructured Utility Environment." Electrotek Concepts, Inc., Washington D.C.

Gates, J. 1999. "Electric Service Reliability Worth Evaluation for Government, Institutions and Office Buildings." *IEEE Transactions on Power Systems*, 14 (1), 43-50.

Gomez, J.C.; Morcos, M.M.; "Coordinating overcurrent protection and voltage sag in distributed generation systems," Power Engineering Review, IEEE , Volume: 22 Issue: 2, Page(s): 16 -19, February 2002.

Gomez, T., C. Marnay, A. Siddiqui, L. Liew, and M. Khavkin. 1999. "Ancillary Services Markets in California." *LBNL-43986*, Lawrence Berkeley National Laboratory, Berkeley. (July).

Greene, N., and R. Hammerschlag. 2000. "Small and Clean Is Beautiful: Exploring the Emissions of Distributed Generation and Pollution Prevention Policies." *Electricity Journal*, 13 (June), 14.

Hadjsaid, N., J.-F. Canard, and F. Dumas. 1999. "Dispersed Generation Impact on Distribution Networks." *IEEE Computer Applications in Power* (April), 22-28.

Hadley, S. W., and J. W. Van Dyke. 2002. "Emissions Benefits of Distributed Generation in the Texas Market." Oak Ridge National Laboratory, Oak Ridge. 15.

Harrison, J. D. 2001. "Micro Combined Heat and Power: Potential Impact on the Electricity Supply Industry." *Electricity Distribution, 2001. Part 1: Contributions. CIRED. 16th International Conference and Exhibition on (IEE Conf. Publ No. 482)*, (4): 5.

Hennagir, T. 1997. "Distributed Generation Hits Market." *Power Engineering*, 101, 18-20.

Hirsch, R. F., and A. H. Serchuk. 1999. "Power Switch: Will the Restructured Utility System Help the Environment." *Environment*, 41 (7).

Hirst, E., and B. Kirby. 1996. "Costs for Electric-Power Ancillary Services." *The Electricity Journal*, 26-30.

Hirst, E., and B. Kirby. 1997a. "Ancillary-Service Details: Operating Reserves." Oak Ridge National Laboratory, Oak Ridge, TN. (November, 1997). 26.

Hirst, E., and B. Kirby. 1997b. "Creating Competitive Markets for Ancillary Services." Oak Ridge National Laboratory, Oak Ridge, Tennessee. (October, 1997). 52.

Hirst, E., and B. Kirby. 1998. "Simulating the Operation of Markets for Bulk-Power Ancillary Services." *The Energy Journal*, 19 (3), 49-68.

Hoskins, W. W. 1998. "Gas Turbines and Recips Vie for Distributed Generation." *Power Engineering*, 102 (9), 42-50.

Iannucci, J., S. Horgan, J. Eyer, and L. Cibulka. 2000. "Air Pollution Emissions Impacts Associated with Economic Market Potential of Distributed Generation in California." *California Air Resources Board Contract No. 97-326*, Distributed Utility Associates, Livermore. (June 2000). 81.

International Energy Agency. 1983. *District Heating and Combined Heat and Power Systems: A Technology Review*, Organisation for Economic Co-operation and Development (OECD), Paris.

Ishii, R. 2001. "Applications and Emissions Profiles of Fuel Cells: Meeting California's Critical Power Needs - the Air Pollution Challenge." *Annual Meeting of the West Coast Section of Air & Waste Management Association*, San Diego, CA.

Jacoby, H. D. 1998. "The Uses and Misuses of Technology Development as a Component of Climate Policy." MIT, Cambridge. (November 1998).

Katolight Power Systems. 2000. *Manufacturer's Technical Specifications for Diesel and Natural Gas Generators.* Minnesota.

Knapp, K. E. 1999. "Exploring Energy Technology Substitution for Reducing Atmospheric Carbon Emissions." *Energy Journal*, 20 (2), 121-143.

Knapp, K. E., J. Martin, S. Price, and F. M. Gordon. 2000. "Costing Methodology for Electric Distribution System Planning." The Energy Foundation. (November 9, 2000).

Koshland, C. P., R. F. Sawyer, D. Lucas, and P. Franklin. 1999. "Evaluation of Automotive Mtbe Combustion Byproducts in California Reformulated Gasoline Volume 3 Chapter 1 of Health and Environmental Assessment of Mtbe." University of California, Berkeley, Berkeley, CA. (March 1999). 47.

Krebs, M. E. 2001. *Comments Regarding the Draft "Model Regulations for the Output of Specified Air Emissions from Smaller-Scale Electric Generation Resources"1.* R. Weston, ed., The Regulatory Assistance Project.

Lents, J., and J. E. Allison. 2000. "Can We Have Our Cake and Eat It Too? Creating Distributed Generation Technology to Improve Air Quality." *00-11-PO-57498-01,* The Energy Foundation. (December 2000).

Lovins, A., E. K. Datta, T. Feiler, K. R. Rábago, J. N. Swisher, A. Lehmann, and K. Wicker. 2002. *Small Is Profitable: The Hidden Economic Benefits of Making Electrical Resources the Right Size*, Rocky Mountain Institute, Snowmass.

Lyon, T. P., and M. A. Toman. 1991. "Designing Price Caps for Gas Distribution Systems." *Journal of Regulatory Economics,* 3 (2), 175-192.

Makelim Power Systems (Kohler Generators). 2000. *Manufacturer's Technical Specification Sheets for Diesel and Natural Gas Generators.* Stockton.

Malins, A. 1998. "Reactive Market." Power Delivery Europe 1998, Conference Proceedings, Power Delivery Europe, London, 8.

Marnay, C., R. Blanco, K. S. Hamachi, C. P. Kawaan, J. G. Osborn, and F. J. Rubio. 2000. "Integrated Assessment of Dispersed Energy Resources Deployment." *LBNL-46082,* Lawrence Berkeley National Laboratory, Berkeley. (June 2000). 121.

Marnay, C., J. S. Chard, K. S. Hamachi, T. Lipman, M. M. Moezzi, B. Ouaglal, and A. S. Siddiqui. 2001. "Modeling of Customer Adoption of Distributed Energy Resources."

LBNL-49582, Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley. (August).

Mayerhofer, P., W. Krewitt, and R. Friedrich. 1997. "Extension of the Accounting Framework: Final Report." Institute of Energy Economics and the Rational Use of Energy (IER), Stuttgart. (December). 348.

McDermott, T.E.; Dugan, R.C.; "Distributed generation impact on reliability and power quality indices," Rural Electric Power Conference, 2002, 2002 IEEE, Page(s): D3 -D3_7, 5-7 May 2002.

Meritet, S. 1999. "Why New Distributed Generation Units Might Transorm Power Industry's Organization: The Case of Gas Microturbines." *The Structure of the Energy Industries: The Only Constant is Change*, Orlando, Florida, 83-92.

Meyers, E., and M. G. Hu. 2001. "Clean Distributed Generation: Policy Options to Promote Clean Air and Reliability."

Office of Energy Efficiency and Renewable Energy. 2000. "U.S. Department of Energy Strategic Plan for Distributed Energy Resources." U.S. Department of Energy, Washington, DC. (September). 34.

Onsite Sycom Energy. 2000. "The Market and Technical Potential for Combined Heat and Power in the Commercial/Institutional Sector.", (January 2000).

Osborn, J., and C. Kawann. 2001. "Reliability of the U.S. Electricity System: Recent Trends and Current Issues." *LBNL-47043*. (August 2001).

Peng Wang; Billinton, R.; "Reliability benefit analysis of adding WTG to a distribution system," Energy Conversion, IEEE Transactions on, Volume: 16, Issue: 2, Page(s): 134 - 139, June 2001.

Price, L. K., C. Marnay, J. Sathaye, S. Murtishaw, D. H. Fisher, Paul, A. G. Phadke, and G. Franco. 2002. "The California Climate Action Registry: Development of Methodologies for Calculating Greenhouse Gas Emissions from Electricity Generation." *ACEEE Summer Study on Energy Efficiency in Buildings*, Asilomar.

Regulatory Assistance Project. 2001. "Model Regulations for the Output of Specified Air Emissions from Smaller-Scale Electric Generation Resources: Model Rule and Technical Support Documents." Gardiner. (November 2001).

Robertson, H. 2001. "Creating a Demand Response Price-Responsive Electricity Load Management Programs." Cambridge Energy Research Associates.

Rubio, F. J., A. S. Siddiqui, C. Marnay, and K. S. Hamachi. 2001. "Certs Customer Adoption Model." *LBNL-47772*, Lawrence Berkeley National Laboratory, Berkeley. (March 2001). 131.

SanMartin, R. L. 1989. "Environmental Emissions from Energy Technology Systems: The Total Fuel Cycle." U.S. Department of Energy, Washington, D.C., (April).

Schunck, R., and J. Lisiecki. 1998. "Taming the Gearbox Roar." *Power Engineering* (September), 52-57.

Scott, W. G. 1998. "Micro-Turbine Generators for Distribution Systems." *IEEE Industry Applications Magazine* (May/June), 57-62.

Shelor, F. M. 1998. "Mini-Merchants for Distributed Generation." *Power Engineering*, 102 (8), 34 - 38.

Soderholm, P., and T. Sundqvist. 2000. "Ethical Limitations of Social Cost Pricing: An Application to Power Generation Externalities." *Journal of Economic Issues*, 34 (2), 453.

Swanekamp, R. 1997. "Distributed Generation: Options Advance, but toward What Pot of Gold?" *Power*, 141, 43-44.

Taylor, C. W. 1999. "Improving Grid Behavior." *IEEE Spectrum* (June), 40-45.

Taylor, T.; “Estimating costs to achieve particular levels of reliability,” Power Engineering Society Summer Meeting, 2001 IEEE, Volume: 1, Page(s): 526 -527, 15-19 July 2001.

U.S. Combined Heat and Power Association. 2002. *Chp Overview*. http://www.nemw.org/uschpa/

Warren, C. A. 1999. "A Survey of Distribution Reliability Measurement Practices in the U.S." *IEEE Transactions on Power Delivery*, 14 (1), 250-257.

Willis, H. L. 1997. *Power Distribution Planning Reference Book*, Marcel Dekker Inc., New York.

Appendix: Survey of Modeling Tools

In this section a list of models is presented. A brief description of each model's capabilities, the website from where it can be accessed, and whether it is freely available or not is also presented. In the Chapter 3 we have indicated the most important models that can be used directly or after appropriate modification to develop an estimate of the DER effects.

1. National Energy Modeling System (NEMS)
NEMS is a large, multi-sector U.S. energy-economy model that projects to the year 2025. NEMS is widely used to analyze the effects of proposed laws and regulations related to energy production and use. Because NEMS considers DER capabilities in the industrial and buildings sectors (residential and commercial), with some in the utility sector, benefits of enhanced DER can be seen in T&D loss reductions, decreases in carbon, NO_X and SO_X emissions, and the effect on the baseload fuels.
Energy Information Administration, www.eia.doe.gov
Availability: Free

2. Integrated Planning Model (IPM)
IPM is an integrated tool capable of focusing on a wide variety of problems and issues facing the energy industry. The IPM model has numerous applications including: Power Market Price Forecasting and Analysis; Environmental Compliance (SO_2, NO_X, CO_2, Hg, and fine particulates); Generating Unit Asset Valuation; Fuel Market Forecasting and Analysis; Retail Deregulation Analysis; Combined Heat and Power (CHP) Market Analysis.
ICF Consulting, U.S. EPA, www.icfconsulting.com
Availability: Proprietary

3. MARKet Allocation (MARKAL)
Like NEMS, MARKAL is also a large energy model designed to provide a means for policymakers to forecast the effects of proposed legislation. Unique to this model is the ability to tailor MARKAL to different regions and countries. This model is able to present the characteristics of regional energy sectors around the world.
Energy Technology Systems Analysis Programme (ETSAP), http://www.ecn.nl/unit_bs/etsap/
Availability: The databases are free however, a software ANSWER is necessary to use this model and there is cost associated with it.

4. Policy Office Electricity Modeling System (POEMS)

POEMS combines the demand and other supply modules of NEMS with a more complex electricity sector. The electric sector was constructed to incorporate the features necessary to analyze policy questions related to: stranded costs, consumer prices, mix of new construction, and interaction with environmental policies. The database contains every power plant in the country, and trade and dispatch is simulated by power control area (roughly 70) for 72 typical time slices in each of 6 seasons. The POEMS model is suited to address integrated modeling issues with a competitive electricity market focus.

OnLocation Inc. Energy Systems Consulting, http://www.onlocationinc.com/ (to assist DOE's Office of Economics, Electricity and Natural Gas Analysis Natural Gas Analysis)

Availability: Proprietary.

5. Tradelec^{TM}

Tradelec^{TM} is a short-term electricity model designed to analyze electricity markets over the next decade. Its scope is narrower and more detailed than the integrated models. Electricity regions are represented at the power control area level as in POEMS, but the temporal representation is much greater. Tradelec^{TM} simulates dispatching of generators and trading by every hour throughout a year. As a result, detailed price duration curves can be constructed for any region. A unique feature is the trading and competitive pricing algorithm which projects prices taking into account not just the generators in a single region, as would a traditional dispatch model, but also all trading opportunities.

OnLocation Inc. Energy Systems Consulting, http://www.onlocationinc.com/

Availability: Proprietary.

6. Integrated Dynamic Energy Analysis (IDEAS)

IDEAS is a simulation model designed for long-term policy analysis of the U.S. energy system. DOE has used it to evaluate potential legislation and long-term strategies over the last twenty years. This model emphasizes the interaction among the various energy sectors, which is important because policies in one sector often have consequences for others. IDEAS has a quick run time. The model has been used for several national energy policy plans and more recently for environmental analyses. IDEAS was the integrating modeling framework for the 1993 Climate Change Action Plan and its update in 1997.

OnLocation Inc. Energy Systems Consulting, http://www.onlocationinc.com/

Availability: Proprietary.

7. Oakridge Competitive Electricity Dispatch (ORCED)

ORCED can analyze any two electrical systems connected by a single transmission link. ORCED uses two load-duration curves to represent the time-varying electricity consumption in each region. The two curves represent peak and off-peak seasons. User

specification of demand elasticities permits ORCED to estimate the effects of changes in electricity price, both overall and hour by hour, on overall electricity use and load shapes. ORCED represents the electricity supply in each region with 26 generating units. The first 25 units are characterized in terms of capacity (MW), forced- and planned- outages (percent of year), fuel type, heat rate (Btu/kWh), variable operations and maintenance costs (based on initial construction cost, year of completion, capitalization structure, and tax rates all expressed in $/kW-yr). The 26th unit is considered energy limited (e.g., a hydroelectric unit).
Oak Ridge National Laboratory, www.ornl.gov/orced/navigate.htm, Stanley Hadley and Eric Hirst (www.ehirst.com)
Availability: Free

8. HAIKU
The RFF Haiku model is a simulation model of regional electricity markets and interregional electricity trade in the continental United States. The model can be used to simulate changes in electricity markets stemming from public policy associated with regulation of the industry to promote competition and environmental benefits. Haiku calculates market equilibrium in each of 13 regions of the country conforming to the National Electricity Reliability Council (NERC) sub-regions, three seasons of the year, and four time blocks within each season. The model uses separate electricity demand curves for each of three sectors of the economy and supply curves that are endogenously determined using fully integrated modules that simulate, among other things, capacity investment and retirement, compliance with NO_X, SO_2, and CO_2 emissions regulations and accounting for mercury emissions, interregional power trading, and coal and natural gas markets. The supply curves are composed of 46 model plants that are each constructed by aggregating the generating unit inventory according to salient technology characteristics. Haiku is designed to be run on a desktop computer.
Resources for the Future, www.rff.org, Dallas Burtraw
Availability: Free.

9. AcuPower
AcuPower includes modules for supply & demand analysis and price forecasts, for a complete range of fundamental and technical indicators. AcuPower can be used to identify trading strategies, market pressure points, gaming opportunities and bidding strategies, to increase profits and reduce risk. Other related models that can be added on to AcuPower or used in conjunction with it are: AcuRisk (based on Simulation engine), AcuOptimizer, AcuVal.
Can also be used to identify stranded assets?
e-Acumen, http://www.e-acumen.com/products/
Availability: Proprietary.

10. UPLAN-NPM (Network Power Model)

UPLAN Network Power Model (UPLAN-NPM) is specifically developed to simulate the electricity markets and the physical dispatch of energy, both for competitive and regulated environments. The model has been used worldwide to support a variety of energy industry functions such as market price forecasting, asset valuation, resource planning and AC/DC load flow. UPLAN-NPM is multi-commodity, multi-area regional electricity model using optimal AC/DC power flow and market algorithms to analyze the economic and physical impacts of competition in a regional power market. It simulates markets and bidding for energy and ancillary serveics using arbitrage opportunity and finding the Nash equilibrium.

Features include:

Day-Ahead Market Model, which simulates energy, all ancillary services and capacity prices using the theoretically correct opportunity cost based bidding. It emulates the day-ahead market common in all regions in North America and abroad.

Real-time Dispatch Model simulates optimal AC/DC load flow and congestion management for all locations.

Provides nodal spot (NSP) or locational marginal (LMP) prices, such as in PJM, NYISO, New England and Ontario as well as zonal prices in California, Texas, Alberta and other power pools. The congestion management algorithm implemented in UPLAN OPF (DC as well as AC) utilizes optimization algorithm similar to that of PJM, NYISO, CAISO and ERCOT.

Fulfils all the modeling requirements of FERC Standard Market Design (SMD) order.

UPLAN can be used for a partially deregulated interconnected area. For example, munis, coops and deregulated utilities can be modeled within one integrated grid.

LCG Consulting, http://www.energyonline.com/products/uplane.asp

Availability: Proprietary.

11. DIStributed Power Economic Rationale SElection (DISPERSE)

DISPERSE estimates the market potential for DER in a specific geographic region. DISPERSE has been used for projects for utilities, equipment manufacturers, government agencies, and research organizations. The number of potential new DER applications by geographic region, SIC code, DER technology type, operation mode, and size is estimated, providing key information on what future markets for DER technologies will look like. This model performs a "bottom-up" analysis, so results can be aggregated in many different ways. A model run begins with a database of industrial and commercial sites, with information on location, facility type, and size. The model assigns electric and thermal load profiles specific to the application and region, and the size of facility is used to "scale" the load profile. Combining this information with DER unit price and performance data, the model performs a life-cycle cost economic analysis, based on the unit life, the cost and performance data, and fuel prices. Baseload electric, cogeneration, and peak shaving operation modes are compared with competing energy prices. The best DER technology option is selected based on the lowest DER competing electricity price. The model then compares the annual cost to generate with costs of purchasing from the grid, and adds the application to the potential market if it beats the grid price. This process is repeated tens of thousands of times, and the results are then aggregated to obtain market potential.

Resource Dynamics Corporation, http://www.rdcnet.com/distributed.htm

Availability: Proprietary.

12. Financial Analysis Tool for Electric Energy Projects (FATE2-P)

Cost Analysis Tool

FATE2-P is a power plant project finance model for calculating Cost of Energy or Internal Rate of Return for alternative energy projects. The FATE2-P model can be used to analyze projects owned by either a non-utility generator or an electric utility. The methodologies the model employs are different depending on the ownership structure. In the case of a non-utility generator, revenues are predetermined as defined by the power purchase contract. The revenue dollars flow from the power purchase contract to the different financial parameters. The risk of ownership then equates to the remaining dollars or the equity recovery and return on equity. In the case of an electric utility, the return on equity becomes a predetermined parameter and the different financial parameters become factors within the revenue requirement calculation.

National Renewable Energy Laboratory, VillagePower, http://www.nrel.gov/international/tools/fate-2p.html

Availability: Free.

13. Cost of Service Model (COSMO)

Cost Analysis tool

COSMO is a tool that computes the area-specific marginal costs resulting from being able to defer, or from having to accelerate, the construction of capacity units due to a change in the capacity requirements. COSMO computes marginal costs in two ways: 1. In situations where a utility does not build capacity to support its load but instead purchases power from the market, the costs of purchase can be considered. In this case, COSMO provides the facility to automatically create data when missing, 2. Or the capacity expansion plans and associated projected load growths for the area can be entered, and COSMO can derive the marginal costs.

The marginal costs can be used as follows:

Rate Design. The marginal cost is the minimum price that a utility can set for a contract. When a customer threatens to leave, the avoided marginal costs indicate the savings that a utility can gain from letting the customer go. In the case of a new customer, the marginal costs represent the incremental costs of having to serve the new load. Using the costs that COSMO generates, a utility can design rates to ensure full cost recovery.

Profitability Evaluations. Since margin equals revenue minus cost, to quantify the margin from a contract, the cost is needed. COSMO provides the marginal costs in this margin quantification.

Different customers in different service areas will have different costs. Since COSMO calculates area-specific costs, COSMO can help a utility quantify the cost of serving a customer, and also determine which customers are more profitable to serve.

Energy and Environmental Economics, Inc., http://www.ethree.com/consulting_products.html
Availability: Proprietary.

14. Distributed Energy Resources – Customer Adoption Model (DER-CAM)
DER-CAM is a customer adoption model that has been developed to look at on-site electricity and heat requirements and develops an optimal plan for customers to meet this requirement at overall minimum cost over a test period. The plan contains a bundle of purchase decisions for self-generation, electricity and heating fuel (typically natural gas) purchases at tariff or power exchange prices, and sales of energy and ancillary services into open markets. This model is going to be extended to simulate customer DER decision making reflective of localized restrictions on DER adoption, such as air quality regulatory restrictions, building code constraints, site limitations, etc. analyzed through a geographic information system layer to DER-CAM.
Ernest Orlando Lawrence Berkeley National Laboratory, eetd.lbl.gov/EA/EMS/, Chris Marnay
Availability: Free, however the software platform on which this model is based is GAMS that needs to be bought in order to use the model.

15. Clean Energy Technology Economic and Emissions Model (CETEEM)
CETEEM was developed to analyze the dynamics of DER and CHP system operation with varying building electrical load profiles, including estimating system performance /efficiency, economics, and lifecycle emissions of criteria pollutants and GHGs. The model currently can conduct economic and performance analysis of stationary PEM fuel cells, fuel cell vehicles (FCVs) used to produce steady or peak power while parked at offices and residences, and hydrogen "energy stations" that would co-produce electricity and hydrogen -- electricity using a stationary fuel cell, and hydrogen to refuel FCVs as an "offshoot" from the same fuel reformer. The capabilities of CETEEM will be improved in the following ways: expand the array of clean energy technologies characterized in CETEEM to also include solid oxide and molten carbonate fuel cells, microturbines, photovoltaic systems, wind turbines, and electrolyzers; develop the CHP analysis capabilities of CETEEM to include space heating and absorption cooling, in addition to the existing water heating module; Develop the capability to analyze hybrid systems, such as wind turbine/electrolyzer/fuel cell systems, PV and microturbine systems, natural gas and PV powered hydrogen energy stations, and others. CETEEM will eventually allow for "microgrid" type configurations where multiple generators and adjacent electrical and heating/cooling loads can be analyzed simultaneously, e.g. to maximize CHP utilization.
University of California Berkeley, Timothy Lipman, Daniel Kammen, and Jennifer Edwards

Availability: As of now this is proprietary. In the future even if it were made free the user would need to purchase MATLAB / Simulink software.

16. D-Gen Pro
D-Gen Pro is a tool for determining the economic feasibility of distributed power generation. D-Gen Pro was developed to quickly evaluate the cost-effective application of on-site and distributed power generation.
Architectural Energy Corporation, www.archenergy.com/dgenpro/default.htm
Availability: $895/-

17. Power Generation Advisor
Power Generation Advisor is designed to help with the economic evaluation and selection of natural gas-fueled power generation equipment. The Advisor is targeted for applications with power requirements of 50 kW to 1 MW. The program is comprised of four interactive modules: Manufacturers, Case Studies, Quick Economics, and Detailed Economics. Manufacturers — Contains detailed information about equipment specifications and contact information for leading manufacturers of natural gas-fueled power generation equipment. Users can modify existing database records, create new records, or delete records. Case Studies —Contains examples of how on-site power generation equipment has benefited specific sites. Users can modify, add or delete information. Quick Economics —Screens applications for economic viability using a few key parameters. Detailed Economics —More carefully analyze specific applications using a wide range of input parameters.
Energy International Inc., www.energyint.com
Availability: Proprietary

18. State-of-the-Art Power Plant (SOAPP)
SOAPP-CT.25 helps you design projects for optimal payback, return, and risk mitigation with seamlessly integrated, accurate modeling of site-specific performance and emissions, equipment sizing, and estimated costs driving a complete financial analysis. SOAPP-CT.25 helps you evaluate the costs and benefits of distributed generation opportunities, solving for return on equity (including IRR and payback period) or for bus bar electricity costs.
Electric Power Research Institute (EPRI), www.soapp.com
Availability: Proprietary

19. energyPro
energyPRO is a software package for the design, optimization and analysis of all energy projects. The software is designed for a wide range of technologies including CHP (gas engines, gas turbines, steam boiler systems etc.), Wind Farms, tri-generation systems incorporating absorption chillers, as well as auxiliary systems such as thermal storage and limited fuel storage. energyPRO is an integrated modeling system that allows the user to carry out a detailed technical and financial analysis of both existing and planned energy projects. The user is able to input a wide range of data on plant, external conditions such as demands and profiles, operating strategies, tariff structures, revenues and operating costs, investments and finance arrangements, plant depreciation and taxation models. The software also allows the user to include the relationships between other variables, such as solar gain or wind, thus allowing very detailed modeling techniques.
Energi- og Miljødata (EMD), www.emd.dk
Availability: Proprietary

20. Contract Evaluator
The Contract Evaluator is a tool for improving utility profitability in an increasing competitive market. Contract Evaluator helps analyze the expected payoff and risk associated with contracts and products. It calculates the risk, return, and risk-adjusted market value of each product. This model evaluates the profitability of portfolios of products and services and allows uncertainty analysis on factors impacting the bottom line. Contract Evaluator has been used to: estimate customer profitability; negotiate the selling or purchasing of other utility contracts; design new supply and delivery contracts; define the minimum acceptable return of a contract based on the risk of the contract; determine the value of hedging the supply costs; determine the profitability impact resulting from expanding the customer base.
Energy and Environmental Economics, Inc., http://www.ethree.com/consulting_products_contract_eval.html
Availability: Proprietary

21. Cogeneration Ready Reckoner
The Cogeneration Ready Reckoner is a software tool designed to assist with preliminary analysis of the technical and economic potential of cogeneration projects. It is supported by information on administrative, legal and environmental issues that should be considered in evaluating cogeneration projects.
Australian Department of Industry, Science, and Resources, Sinclair, Knight, Merz, http://www.industry.gov.au
Availability: Free.

22. RECIPRO

RECIPRO enables plant engineers and consultants to select and optimize cogeneration systems for hotels, hospitals, institutional buildings and small industrial applications.

RECIPRO Features:
Reciprocating Engine Database RECIPRO comes with built-in descriptions of a variety of reciprocating engines and small gas turbines. Over one hundred diesel and gas engines from 40 kW to 3 MW are included. The fuel consumption, exhaust characteristics, and heat recoverable from jacket cooling water are given at full and part load for each engine. Additional engines may be added to the database file.
Flexible Units Uses U.S. or Metric. Can use any currency.
Monthly Load Variations Monthly heat and electric load requirements and costs can be input from utility bills. RECIPRO uses this information to model energy consumption and savings with any proposed cogeneration system.
Daily Load Variations Electrical and thermal load variations can be defined over the daily 24-hour cycle for each month. These user-defined load curves can be saved for later use. Alternatively, RECIPRO can develop appropriate daily load variations from monthly energy consumption data.
Cogeneration Control Strategies RECIPRO can evaluate thermal following, electric following, dual (thermal and electric) following, or flat-out control strategies.
Absorption Chiller The program can analyze the effect of substituting absorption chillers for electrically driven units to make better use of cogenerated heat during the summer months.
On-Peak and Off-Peak Pricing RECIPRO considers different buying and selling prices for electricity at on-peak and off-peak hours. It also recognizes the demand portion of the electricity bill and the effect of plant outages on savings.
Automatic Scanning RECIPRO can be instructed to automatically scan through the engine database, compute the annual savings with each engine model, and summarize the systems that generate maximum savings based on the energy load.
Internal Rate of Return The program computes a project's annual cash flows and return on equity, based on various cost, tax and financial parameters.

Thermoflow Inc., http://www.thermoflow.com/index.htm

Availability: Proprietary.

23. PDE: Plant Design Expert

PDE is an intelligent, knowledge-based expert system that creates inputs to GT PRO, a widely used program for combined-cycle and cogeneration design. It then runs the GT PRO computational module and presents the resulting cycle as graphic and text outputs. The user enters site conditions and constraints, power and process steam requirements, and economic tradeoff between cost and efficiency. PDE outputs a number of potential system designs that meet the input criteria, and creates a detailed cycle heat balance design.

Thermoflow Inc., http://www.thermoflow.com/index.htm
Availability: Proprietary.

24. HEATMAP
HEATMAP 5 is a Windows®-based software tool that aids energy planners in designing and evaluating district energy systems, including combined heat and power (cogeneration) and geothermal applications. HEATMAP provides computerized simulations of district heating and cooling systems, allowing users to analyze the performance of existing networks as well as model proposed systems, expansions, or upgrades. HEATMAP 5 (standard version) operates in either metric or inch-pound units. HEATMAP automates many of the labor-intensive activities associated with district energy feasibility assessments. HEATMAP models an initial installation and an unlimited number of alternative scenarios including planned expansions, contractions, and changes to system operating parameters (e.g., steam to hot water). HEATMAP allows for optimizing the capacity and operating strategy of a production plant or system (e.g., multiple plants) and determining the proper distribution pipe sizes to carry the load during scenario evaluations. It can also determine maximum coincident loading on any pipe in the network and analyze consumer or system loads present during any hourly interval of a model year. HEATMAP can also evaluate long-term environmental impacts of existing and proposed systems. Key program features include the capability to analyze air-pollutant emissions, including carbon dioxide, from existing energy sources; compare those levels with air quality that would result after implementation of district energy systems; and determine the effect of environmental taxes.
Washington State University Cooperative Extension Energy Program, http://www.energy.wsu.edu/software/heatmap.htm
Availability: Free.

25. Hybrid Optimization Model for Electric Renewables (HOMER)
HOMER is a simplified optimization model for designing power systems for remote loads. It performs a full hourly simulation of the performance of user-selected systems that include PV, wind, batteries, inverters, and fuel-fired gen-sets and various combinations of these technologies. It uses life cycle cost to rank order these systems as well as grid extension. Automatic sensitivity analyses can be performed to evaluate the sensitivity of the system design to key parameters, such as the resource quality or component costs.
National Renewable Energy Laboratory, VillagePower, http://www.nrel.gov/international/tools/HOMER/homer.html
Availability: Free.

26. Hybrid2
This technical model simulates the performance of various wind/photovoltaic/diesel hybrids. It examines the long-term performance of comparable systems.
National Renewable Energy Laboratory, VillagePower, http://www.nrel.gov/international/tools/hybrid2.html
Availability: Free.

27. Village Power Optimization Model for Renewables (ViPOR)
ViPOR is an optimization model for designing village electrification systems. Given a map of a village and some information about load sizes and equipment costs, ViPOR decides which houses should be powered by isolated power systems (like solar home systems) and which should be included in a centralized distribution grid. The distribution grid is optimally designed with consideration of local terrain.
National Renewable Energy Laboratory, VillagePower, http://www.nrel.gov/international/tools/vipor/vipor.html
Availability: Free.

28. **mGrid** Analysis Model
mGrid is based on a general method for large-scale electric power system multiphase power flow analysis. The method has three unique characteristics: (a) each system component, (such as a transmission line, a generators, a load, etc) is represented by a physically based model in direct phase quantities and without any approximating assumptions, such as phase to phase symmetry, balanced voltages and currents etc. Thus, effects of system imbalance and asymmetries are accurately represented. (b) The model is quadratized, i.e. any nonlinear mathematical model of a system component is converted into a set of second order equations with the introduction of appropriate transformations, and (c) the method introduces the composite node concept, which enables the representation of system neutrals, ground wires, etc. and thus the study of transfer voltages to grounded structures (safety assessment). The solution method of the overall model is based on Newton's method. Since the model is quadratized, Newton's method provides fast (quadratic) and reliable convergence. (d) The mGrid modeling environment is based on an object oriented organization. It is integrated with a graphical user interface with extensive I/O capabilities. It includes a CAD-style schematic editor, which allows direct manipulation of the study system parameters in single line diagram form. The present computer code includes a limited number of device models, specifically: Constant Voltage Source, Constant Power Source, Constant Impedance Load, Constant Power Load, Multiphase Transmission Line (Overhead), Induction Motor The **mGrid** Analysis Model permits the study of interaction of the complex control schemes of power electronic interfaces and the power grid as well as the impact of distributed energy resources on the safety of the system.

Georgia Institute of Technology, Sakis Meliopoulos
Availability: Free.

29. Remote Power Applications Model (RPAM)
RPAM has been developed to assist in the evaluation of remote power systems. The model can evaluate the economics of any combination of photovoltaics, batteries and generators. RPAM was developed to assist distribution planners and engineers in evaluating the economics of remote power systems (not connected to the grid). RPAM compares the economies of remote power systems with a line extension. The model uses an engineering simulation of a specified remote power system and line extension, and then performs a standard utility revenue requirement calculation to evaluate the economics. The model calculates the stream of revenue requirements to support the capital investments, O&M and other annual payments. The line extension model uses the standard engineering limits of voltage drop and maximum capacity to size the line appropriately. The line extension and remote power system are compared on the basis of the life cycle cost of their two revenue streams.
Energy and Environmental Economics, Inc., http://www.ethree.com/consulting_products_rpam.html
Availability: Proprietary.

30. Building Energy Analyzer
.
Building Energy Analyzer can estimate annual or monthly loads and costs associated with air-conditioning, heating, power generation, thermal storage and cogeneration systems for different building types in different regions. The model can prepare side-by-side economic comparisons of different energy options. It performs economic analysis for the customer's utility rates, location, and building type.
InterEnergy, http://www.interenergysoftware.com
Availability: Proprietary.

31. The Virtual Environment (VE)
Building design.
This is a building design software for architects, engineers, and building managers that evaluates the performance of the building throughout the design process. Among various other capabilities, VE can be used to calculate energy consumption and costs.

Integrated Environmental Solutions Ltd, www.ies4d.com
Availability: Proprietary.

32. ADEPT
The ADEPT artificial intelligence system uses a neural network and genetic algorithm to make buildings "smarter." ADEPT helps optimize the performance and minimize the operating costs associated with electric and gas-powered cooling systems. Taking into consideration weather, building usage, and electric rate information, ADEPT automatically develops an operating plan to meet cooling requirements at the lowest cost. ADEPT can help utilities operate more efficiently (which can reduce emissions and conserve natural resources) and pass savings on to their customers.
Science Application International Corporation, www.saic.com/neuralnet
Availability: Proprietary

33. Energy-10
Building design.
Energy-10 integrates daylighting, passive solar heating, and low-energy cooling strategies with energy-efficient shell design and mechanical equipment. It enables designers to make good decisions about energy efficiency early in the design process. Energy-10 was developed with a building industry task force that included architects, engineers, builders, and utility representatives. The program is geared toward buildings of 10,000 square feet or less
National Renewable Energy Laboratory, VillagePower, http://www.nrel.gov/buildings/energy10/
Availability: Free.

34. WindMil
WindMil's expanded model can analyze a system by feeder, substation, or the entire system. WindMil features a direct interface to LightTable (another proprietary software for manipulating time-current curves) for Protective Device Coordination. The user assigns a LightTable curve to each device modeled in WindMil and then selects a series of devices to display with automatic shifting for any number of inline transformers. No additional modeling is required. The interface works directly from existing WindMil and LightTable databases without the need to create or define an intermediate database for either. WindMil also allows GIS produced graphic files to be displayed behind the WindMil engineering model. LandBase converts the following formats into WindMil: AutoCAD DWG, AutoCAD DXF, MicroStation DGN, ESRI Shape Files, MapInfo Vector, TIFF, Bitmap, Blue Marble, JPEG and Vector Product Format. All formats are connected directly without the need to convert or import. Many different layers can be connected to create a composite view. WindMil can report in graphical display or tabular reports. In addition to modeling radial

electrical systems, windMil can also model looped systems.

Milsoft Integrated Solutions, http://www.milsoft.com/windmil.html

Availability: Proprietary.

35. Area Investment Models (AIM)

The Area Investment Models (AIM) have been designed to incorporate competitive concerns into the traditional T&D planning process. The AIM suite of programs helps design cost effective T&D plans, incorporating risk assessment into design process, and identifying area-specific DER potential.

AIM Planner assists planners in the design of capacity expansion plans. The model helps planners to balance capacity investment costs with the potential cost of unserved energy under load growth uncertainty and various reliability criteria.

AIM DELTA can evaluate multiple areas at one time, and can perform quick or detailed analyses.

AIM Screener has been developed to incorporate profitability and risk assessment into the evaluation of competing T&D plans. Screener summarizes cash flows under a number of load growth scenarios, going beyond the traditional static assessment of revenue requirement under the forecasted load.

Energy and Environmental Economics, Inc.,
http://www.ethree.com/consulting_products_aim_suite.html

Availability: Proprietary.

36. Power System Blockset 2.0

Power System Blockset can simulate graphical models in a comprehensive design environment and allows the user to run multi-domain simulations of electrical power components and their controllers. Power System Blockset is suited to the development of complex, self-contained power systems. It utilizes Simulink's variable step integrators and precise event location techniques to allow engineers to run highly accurate simulations of power systems. Power System Blockset is a powerful solution that enables users to model the generation, transmission, and distribution of electrical power with its associated control systems. In addition, the blockset provides functionality for analyzing flow within power utility networks and migrating developed control system models to TEQSIM's Hypersim digital simulator for real-time power grid simulation.

Mathworks, http://www.mathworks.com

Availability: Proprietary.

37. CAT I

CAT1 simulates a single generating unit or a system of units for up to 40 years, like a traditional production cost model that uses a market-based dispatch. It forecasts revenue and expenses, and helps determine the profitability of potential capacity acquisitions or sales.
CAT I incorporates a detailed profit-based unit commitment and dispatch. A generating unit simulation may be as simple as a capacity and dispatch cost or have detail to reflect: Start-up cost including cold and hot start periods, minimum run and shutdown times, ramp up and down rates, must run periods, separate fuel and transportation costs, variable O&M costs, and emissions removal cost and allowance prices.

CAT I uses the hourly market price of energy to determine the most profitable period that each generating unit should operate under the specified operating costs and constraints. Results include operation and financial reports by unit, plant, and system that are easily transferred to other software for additional analysis.

Utility Systems Associates Inc., http://www.usacats.com/CatI.html

Availability: Proprietary.

38. SAFEPLAN

SAFEPLAN is a powerful integrated planning model developed by Policy Planning Associates. SAFEPLAN is a microcomputer-based, least cost/integrated resource planning program that serves as a screening tool and resource evaluator for demand-side management (DSM), new generation, and third party purchases. The program estimates the costs and benefits of all programs under consideration by the utility, and compares them to each other on a consistent basis.
Using SAFEPLAN, the utility planner can formulate least cost planning strategies, evaluate individual projects, schedule new capacity, and create reports documenting the cost effectiveness of planning decisions. SAFEPLAN can model any number of units, including conventional hydro, pumped storage hydro, multi-stage combined cycle, third party purchased power, and DSM.

Brooks & Associates, http://www.brooksassoc.com/resource.html

Availability: Proprietary.

39. RAMELEC

Reliability Assessment

RAMELEC is an electricity reliability assessment model that computes the frequency and magnitude of capacity shortages that might be expected in an area given assumptions about supply and demand. Using Monte Carlo simulation, the model determines the outages of generating units for each hour in the study. The difference between the demand forecast and the supply forecast for each simulation provides the probabilistic estimate of supply shortages.

OnLocation Inc. Energy Systems Consulting, http://www.onlocationinc.com/
Availability: Proprietary.

40. Product Designer
Price Volatility
This model designs products that hedge against volatile market prices. Product Designer can quantify impacts on an energy supplier's revenue and customers' bills. This model developed by Energy and Environmental Economics, Inc., allows energy suppliers to design, price, and evaluate forward contracts for electricity.
Energy and Environmental Economics Inc., http://www.ethree.com/consulting_products_product_des.html
Availability: Proprietary.

41. PQSoft
Power Quality Analysis
PQSoft® is a family of software programs for power quality and energy efficiency analysis of electric power transmission and distribution systems. These tools enable you to assess power system performance in terms of quality and energy usage.
Electrotek Concepts, http://www.pqsoft.com/
Availability: Proprietary.

42. p-ELF
Demand Forecast
p-ELF is a multivariate statistical model that uses seasonal, structural and weather data to forecast load levels on a probabilistic basis. p-ELF can be tied to a user specified weather forecast or rely on OnLocation's NOAA 30-year database of hourly frequency distributions of weather data to produce a "normal weather" load shape. This NOAA database can also be used to estimate alternative "severe" weather load estimates, for example 1 in 10 year forecasts. To further refine the hourly load forecast, p-ELF can be benchmarked to a published energy forecast for the period under study.
OnLocation Inc. Energy Systems Consulting, http://www.onlocationinc.com/
Availability: Proprietary.

Natural Gas Infrastructure

43. ArcGIS
Natural gas infrastructure.
ArcGIS has 30 different datasets that are used to evaluate potential locations for CHP. All spatial data is compiled into a geodatabase using ArcView 8 for ArcGIS. The model includes standard scoring and ranking procedures for industrial facility location analysis. Individual variables are measured under broad categories including environmental sensitivity, zoning and land use, heat loading, utility infrastructure access, electricity

sensitivity, zoning and land use, heat loading, utility infrastructure access, electricity demand, and local economic development potential. An automated process for measuring the spatial variables within ArcGIS and mapping the results was developed using the ArcObjects programming language to customize an application for ArcGIS. Initial presentation of results is expected in the summer 2002.

Applied GIS, www.appliedgis.com

Availability: Proprietary.

44. UPLAN-G: Gas Procurement and Competitive Analysis System

Natural gas infrastructure.

UPLAN-G contains five primary simulation modules: a commodity cost module for short-term resource portfolio optimization; a commodity cost uncertainty module for risk analyses; an integrated optimization module for determining the optimal resource mix for current and future years using existing and planned resources; a market module for gas price forecasting; and a strategic finance module for predicting revenue requirements.
UPLAN-G supports hourly and daily time-steps for all functions and can be linked to UTRACK, LCG’s gas deals data entry and accounting tool, as well as UPLAN-E, LCG’s electricity market model.
UPLAN-G can be used for these types of analyses:
Gas Supply: System Operations and Resource Optimization
Daily Gas Dispatch Optimization
Optimal Supply Portfolio Selection
Transportation Cost Minimization
Capacity Release & Pipeline Sizing
Hedging & Uncertainty Analysis
Rates, Revenue, and Finances
Revenue Requirement & Cost of Service
Financial Projections
Project Accounting & Taxes
Marketing and Demand Analysis
Demand Forecast & Marginal Cost
Market Devlopment & Pricing
Benefit Cost Analysis
Optimal DSM Programs Selection

45. Urban Airshed Model (UAM)

Regional air pollution model.

The Urban Airshed Model (UAM) is a "Eulerian" 3-dimensional grid photochemical model. It uses meteorology, air quality, terrain and emissions data and the Carbon Bond IV mechanism to derive concentrations for 23 species. It simulates transport from cell to cell, both horizontal and vertical diffusion. The UAM Modeling System consists of a core model (UAM), preprocessors for control, meteorology, and initial/boundary conditions, the Emissions Preprocessor System (EPS), the Diagnostic Wind Model (DWM), and the ROM-UAM Interface Program System.
Other similar models available are:

RPM RADM CMAQ AERMIC MM3
U.S. EPA website: http://www.epa.gov/scram001/tt22.htm
Availability: Free.

46. BLP (Bouyant Line and Point Source Model)
Local air pollution model.
BLP is a Gaussian plume dispersion model designed to handle unique modeling problems associated with aluminum reduction plants, and other industrial sources where plume rise and downwash effects from stationary line sources are important. Other similar models available are: CTDMPLUS ISC3 OCD RAM CALPUFF CALINE3 CDM2
U.S. EPA website: http://www.epa.gov/scram001/tt22.htm
Availability: Free.

47. Tracking and Analysis Framework (TAF)
TAF links together into an integrated framework the key acid deposition components of pollutant emissions; control costs; atmospheric transport and deposition; environmental effects on visibility, lakes, soils, and human health; and valuation of these effects. TAF has been developed by a collaboration of ten different organizations, including national laboratories, universities, nonprofit organizations, and consulting firms. Each component has been developed by a different group of scientists with special expertise in those issues. TAF is not a single model, but rather a flexible framework for modeling an integrated assessment. As science progresses, new understanding will justify revised or new models. As new policy questions emerge, information needs will evolve. To meet these challenges, the TAF framework is designed to accept replacements so that other modules can be slotted in to replace existing modules or to expand the model to address new issues. TAF provides a framework that allows a variety of models to be developed and coexist in a flexible, yet coordinated, manner.
Lumina, www.lumina.com/taflist
Availability: Free.

48. Local Scale Modeling of Human Exposure Microenvironments

EPA is working on a project to specifically improve the methodology for real-time site specific modeling of human exposure to motor vehicle emissions. The goal is to develop improved methods for modeling air pollution from the source through the air pathway to human exposure in significant microenvironments. Local-scale modeling refers to spatial scales from the size of an individual vehicle to the order of 1 km.

The first component of the modeling framework is real-time site-specific motor vehicle emission models capable of capturing real-world emissions. Development of a real-time Microscale automobile emission Factor model for Carbon Monoxide (MicroFacCO) was completed. Development of a particulate matter version should be completed during 2001. The emission rates calculated from these models can be used in conjunction with a roadway air dispersion model to estimate the ambient concentrations near roadways for a range of traffic fleet and meteorological conditions.

The second component will be a local-scale meteorological and air dispersion model to provide ambient air concentrations resulting from transport and other human activities. Refined modeling using Computational Fluid Dynamics (CFD) simulations and measurements are being applied to develop refined air dispersion models for linkage to a roadway microenvironmental model. This modeling framework will help to establish the direct relationships between source-to-exposure concentrations specific to the particular exposure microenvironment (e.g., standing by the roadside or actually inside the vehicle, inside the moving vehicle , living nearby a roadway). Output from this deterministic modeling of microenvironmental concentrations and measured microenvironmental concentrations for a range of scenarios will be used to develop distributions of potential exposure that is probabilistically-based to support population-based human exposure modeling.

U.S. EPA website: http://www.epa.gov/scram001/tt22.htm

Availability: Free.

49. PowerWorld® Simulator

PowerWorld® Simulator is an interactive power simulation package designed to simulate high voltage power system operation. Simulator can be used to give an analyst a comprehensive look at issues surrounding electrical power flows in a transmission grid. Simulator uses a full Newton-Raphson algorithm, with non-divergence control. Simulator can solve power systems with up to 60,000 buses and an almost unlimited number of lines. Other features include: sortable list displays to view all or a subset of the various devices in the system (such as buses, generators, transmission lines, dc lines, switched shunts, areas and zones); the ability to easy scale the load or generation; the ability to create electrical equivalents; the ability to do economic dispatch for any area; the ability to set up load schedules; the ability to graphically compare two different cases; the ability to generate and graphically show PTDFs; and the ability to graphically create or modify a case.

http://www.powerworld.com/

Availability: Free.

50. POWERWEB

POWERWEB is an interactive, distributed, Internet-based simulation environment for experimentally testing various power exchange auction markets using human decision makers. As with most existing and proposed electric power markets, POWERWEB assumes the presence of a central agent acting as an independent system operator (ISO) to assure the reliable operation of the physical power system. The POWERWEB environment is designed to run unit commitment and optimal power flow routines against load forecasts in order to provide generation schedules such as those that might be assigned by a Power Exchange (PX).

In the current implementation of POWERWEB, the ISO/PX receives offers to sell power from independently owned generation facilities. Based on a forecasted load profile and the offers submitted by the generators, the ISO computes the amount of power to be produced by each generator and the corresponding price, such that the demand is met while satisfying all of the system's operational constraints. The method used to solicit offers and the mechanism that determines prices are dependent on the market model being examined.

http://stealth.ee.cornell.edu/powerweb/

Availability: Free.

51. Capital Asset Pricing Model (CAPM)

The Capital Asset Pricing Model uses a variation of discounted cash flows; only instead of the user giving a "margin of safety" and being conservative in earnings estimates, a varying discount rate is applied that gets bigger to compensate for the investment’s riskiness. There are different ways to measure risk; the original CAPM defined risk in terms of volatility, as measured by the investment's beta coefficient. The formula is:

$K_c = R_f + \text{beta x} (K_m - R_f)$

Where,

K_c is the risk-adjusted discount rate (also known as the Cost of Capital);

R_f is the rate of a "risk-free" investment, i.e. cash;

K_m is the return rate of a market benchmark, like the S&P 500.

K_c can be interpreted as the expected return rate one would require before one would be interested in this particular investment at this particular price. The idea is that investors require higher levels of expected returns to compensate them for higher expected risk; the CAPM formula is a simple equation to express that idea.

This is a method that can be easily programmed on a suitable software platform to perform analysis.

Availability: Free.

52. Electricity Asset Evaluation Model (EAEM)

Using as inputs existing generation, transmission, and distribution system characteristics along with projected loads, EAEM can determine when and where new generation, transmission and distribution assets should be located to meet user-specified goals that include, meeting projected system loads, facilitating technology choices, determining costs and benefits of alternative options or scenarios, alleviating transmission and/or distribution system congestion, and increasing system reliability.

The model optimizes the selection of a new asset based on a comparison of its total costs (capital and expected operating) relative to the avoided costs of serving projected loads with other existing and new assets. Since the model compares all options simultaneously it selects the assets that minimize total system costs, generation, transmission, and distribution. New generation options can include both large, central station plants and smaller distributed generation options.

In calculating expected operating costs, the EAEM considers the random nature of generator outages and load. Consideration of these random elements means that the model more accurately simulates the dispatch of base-load and peaking units, and thus yields a more accurate estimate of expected costs on which asset addition decisions are based.

The capital and operating costs avoided by installing a given asset are defined to be its benefits. Due to the variation in such costs as land use, fuel and labor, together with location-specific transmission and distribution constraints, these benefits differ by time and location. If the system is defined to include the transmission grid, the model maximizes these benefits by locating new assets where they will alleviate transmission or distribution congestion and offset the highest capital and operating costs. Thus, the benefits of alleviating congestion are implicitly attributed to the associated investment.

While capital and operating costs represent the cost of serving load, there are also costs to the customers of unserved energy. By assigning very high costs to unmet critical loads, the EAEM can increase the reliability of power supply to these loads.

Flexibility in the EAEM framework allows the model to accommodate different levels and sources of input detail, and to examine a wide range of problem sizes.

Energy Resources International, Inc.

Availability: ?