Planning Energy-Efficient and Eco-Sustainable Telecommunications Networks

H. Scott Matthews, Thomas B. Morawski, Amy L. Nagengast, Gerard P. O’Reilly, David D. Picklesimer, Raymond A. Sackett, and Paul P. Wu

Global warming and escalating energy costs have provided the impetus for a worldwide movement to reduce energy consumption and the associated environmental impacts arising from carbon emissions. Telecommunications providers are contributing to this effort by assessing the impacts of their products and offering telepresence and enhanced data services to their customers to reduce the need for travel and shipping. While greater use of services like these results in lower worldwide energy needs, higher energy usage by the telecommunications providers themselves will occur unless they make changes to their operations environment. There are many ways to reduce the energy usage and environmental impact of telecommunications networks. Choosing the most appropriate direction requires planning. Developing an optimal energy reduction plan requires an understanding of the current network, future service offerings, and the technology roadmap, along with numerous additional data to support the analysis. The complexity of the planning process led Bell Labs to develop the Telecom Power Estimator. This paper describes energy usage in telecommunications networks, identifies possible network changes to reduce energy usage, evaluates the potential of alternative (solar and wind) energy use in telecommunications, and discusses the business case (including government incentives) for implementing environmental impact reductions—all in support of the eco-sustainability planning process. The Telecom Power Estimator will also be introduced, along with a discussion of how it is used to develop a holistic, cost-effective energy efficiency and eco-sustainability plan for a telecommunications network operator.

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Introduction

Innovations in science and technology have allowed the telecommunications industry to expand services, reduce prices, and grow to meet the ever increasing demands from other sectors—sectors that increasingly rely on telecommunications to help them work efficiently while reducing their energy consumption. The current worldwide focus to reduce energy consumption and ecological impacts is adding...
another dimension to the business cases for new network technology, implementation of energy-saving systems, and installation of green alternative power solutions. Choosing among the various green systems, options, and power sources requires a plan based on network architectures, service offerings, customer base, and geographic location. This is a challenging, multi-dimensional planning process.

Advances in network architectures, telecommunications network equipment, and building services infrastructure have resulted in a significant increase in the number of information bits that can be communicated per unit of power. While there are numerous energy-saving options for network operators, not all are viable from a business perspective because of the capital investments required. Complicating the choices further, business factors such as wireline or wireless deployment, new build or existing facilities, growth rates, government incentives, geographic location, and consumer sentiment make it even more difficult to decide whether energy reduction initiatives are a good investment. When energy-reduction initiatives are implemented, power consumption may be reduced to the point that eco-friendly power options become viable. Then another set of questions must be answered, again related to growth, geographic location, government incentives, and consumer sentiment. The need for these multi-faceted analyses in developing an eco-sustainability plan prompted development of the Bell Labs Telecom Power Estimator, which is used to evaluate the viability of various power reduction plans.

This paper will first describe how energy is used in telecommunications networks today. The differences between wireline and wireless network power usage are highlighted as well as the business perspectives related to energy-saving initiatives in new build (greenfield) versus existing infrastructure (brownfield) settings. Various energy efficiency initiatives are described for both wireline and wireless networks. Eco-friendly power sources—wind and solar generation on-site—as well as purchasing green power from the grid are then considered. An overview of the Bell Labs Telecom Power Estimator is provided along with a discussion of the factors involved in the business decision to deploy these technologies and example business case results.

**Energy Usage in Telecommunications Networks**

Bandwidth demands in telecommunications networks have increased at unprecedented levels since the turn of the century, growing annually at...
an average rate of 50 to 60 percent and exceeding 100 percent growth during some years [2, 5]. With new services like high-definition (HD) video and gaming, coupled with the explosion of applications coming online, there is no leveling of demand in sight. Without changes in network architecture, network equipment, and power sources, network operator energy demands, along with their associated energy costs, will be immense [2]. Network operators are seeing this trend and are engaged in efforts to stop the trend of rising telecom energy demands. With so many options for reducing their eco-footprint, and considering the challenge of implementing changes while remaining profitable, planning a sensible, ecologically friendly path forward is often a formidable task.

Planning for reducing network energy usage and improving eco-friendliness requires an understanding of where and how energy is currently used. At a high level, networks are hierarchical in nature, designed with a relatively few core nodes that host servers, switches, and interconnect/routing equipment, and many more smaller sites distributed closer to the homes and businesses being served. This means that when energy reduction opportunities are identified beyond the network core, there are many opportunities to replicate the savings. This paper will focus on identifying energy reduction and alternative power opportunities applicable toward the edge of wireline and wireless networks because of the multiplying factor that results from the vast number of central offices and base stations that are either currently deployed or being deployed. This section provides an overview of how the power is used in these locations, setting the stage for understanding the value of various energy-efficiency options and alternative power opportunities available.

Power Consumption at the Wireline Central Office

The use of passive optical networks (PONs) and remote node (RN) systems in wireline networks is changing the energy usage footprint in wireline networks. Both architectures move the final edge network elements outside of the central office, either into outside cabinets near the homes or businesses served or into the homes or businesses themselves [5]. This eases the power requirements for the central office and provides new opportunities for the use of eco-friendly power sources, as described later in this paper.

An average traditional central office requires approximately 1,500 kW of power, with an energy usage breakdown of:

- 42 percent network equipment,
- 35 percent cooling, and
- 23 percent rectifiers and other direct current (DC) power.

These estimates are based on a Bell Labs analysis described later and assume legacy time division multiplexing (TDM) switching equipment as well as other gear (e.g., digital subscriber line access multiplexers [DSLAMs]) in the central office (CO) building serving 100,000 subscribers, 20 percent of which have digital subscriber line (DSL) service. The CO has typical power distribution, rectifier, and cooling equipment with their associated inefficiencies. For example, it is common for TDM switching equipment to operate at a 50 percent fill rate (active lines versus engineered lines) today. Couple this with aged rectifiers operating at less than 60 percent efficiency (resulting in 40 percent wasted heat) taxing a dated, inefficient cooling system, and it is easy to see numerous opportunities to reduce energy usage. Reductions can climb into the range of 40 to 80 percent. As is shown in the breakdown above, cooling is often one of the two largest contributors to the total power usage in a central office. Reducing energy consumption in the form of wasted heat from network equipment, rectifiers, and other sources can often provide a doubling of the savings when considering the reduced cooling load.

Power Consumption in the Wireless Base Station

High-level wireless architectures feature base stations deployed near subscribers, similar to the PON and RN access equipment in wireline networks. Technology is changing rapidly for wireless, significantly changing the power requirements of the base station. These improvements increase the viability of using eco-friendly power here as well. A typical three-sector legacy code division multiple access (CDMA) base station presenting a 5 kW overall power load has an energy usage breakdown as shown in Figure 1.
Figure 1 shows that the radio frequency (RF) power amplifier (PA) uses most of the power in the base transceiver station (BTS), even more than the baseband equipment. Air conditioning, not shown in the figure, is typically also one of the main power sinks, consuming 20 percent or more of the energy of the base station. This parameter is highly variable, as discussed below. The power supply system, while not using nearly as much energy as other components, is still a consideration when planning energy efficiency steps.

Location of the PA relative to the baseband equipment causes the largest variability in power usage in the base station. The PA produces so much heat that it doubles the cooling load if it is installed near the baseband equipment. If there is an option to install the PA outside, nearly half of the cooling load is eliminated, along with the associated energy cost. An added power benefit is the closer the PA is placed to the antenna, the less output power is required from the PA due to reduced transmission line loss. The ideal option, if feasible, is to install the PA on the tower, right next to the antenna.

The cascading of power loads: (i.e., indoor PA + cable loss = more PA power and more cooling load) is referred to as a power chain. This concept is important when planning energy reduction and is described in more detail in a later section.

Considerations for Wireline and Wireless Efficiency Options

Telecommunications network service-providing equipment normally consumes the most power in a network followed by the supporting elements: cooling equipment, power rectifiers, DC-to-DC converters, and other miscellaneous support equipment. Intuition would suggest that the service-providing equipment would consume more power in the network than the supporting equipment, but this is often not the case. The sum of the all-supporting equipment typically consumes more power than service-providing equipment.

The nature of the wireline and wireless business landscapes is currently quite different, and this affects the business viability of many eco-friendly initiatives. The wireline market for traditional voice services is shrinking (except for competitors to the traditional telecommunications providers). Solutions that compete with new video and triple-play services are succeeding to some extent, but these network architectures do not require nearly as much central office equipment as traditional voice services. This adds both positive and negative attributes to the case to reduce the energy usage footprint. It is a benefit because there is often equipment that is powered but is no longer providing services or equipment that could easily be eliminated by consolidation of subscribers onto other under-utilized equipment. Once the consolidation is completed, less power and cooling are required. These can be further improved by migrating to more efficient rectifiers and cooling systems. The negative side is that even though the business case for moving to more efficient solutions can be quite good, network operators are often reluctant to invest in infrastructure changes when their business in that area continues to erode.

The wireless market is quite different, though, seeing strong growth and customer demand for new services. This too provides both positive and negative attributes for the case to reduce the eco-footprint. It is a benefit because network operators are actively seeking new strategies to reduce the power costs appearing on their bottom line by looking at both power reduction and eco-friendly energy sources. The downside
is that demand for new services results in relatively short product lifetimes before the next technology cannibalizes the existing technology, making network operators hesitant to change anything until the next product cycle is deployed.

Issues like these cause a real challenge when planning for improved energy efficiency and eco-friendliness. The Bell Labs Telecom Power Estimator (TPE) was developed to make high-level analyses of these complex planning scenarios much more tractable. Its analyses are based on best-estimate models developed from experience in the field as well as data from actual energy efficiency optimization engagements performed by Alcatel-Lucent in the North American market. The TPE was used to develop the examples in this paper.

Rationale for Reducing Central Office Energy Usage

Energy reduction initiatives can have a significant impact on the total power consumed by a network. The savings result from deploying energy efficient equipment and the consolidation of telecommunications locations, along with the subsequent reductions in cooling of the buildings. New telecommunications network architectures also permit consolidation of functions into fewer locations. Application of these concepts to a network is demonstrated below.

Alternatives for the wireline network which vary the percentage of switch line consolidation for voice switches throughout a large telephone company (50 million total lines of service) are considered in the following example. The total power usage for these lines is approximately 2.7 billion kilowatt hours (kWh) per year, based on Bell Labs TPE data. With the advent of next-generation networks [3], thousands of switches as well as numerous central offices serving these lines can be consolidated. In addition to this consolidation, energy initiatives such as replacing older rectifiers with newer, more efficient ones may be deployed. As a third step, still other energy initiatives that replace older, less efficient systems with modern, efficient systems may be installed (e.g., more efficient cooling systems, or even a move to assist grid-power with renewable energy systems based on solar, wind, or fuel cells). Roof-mounted solar energy systems for generation of electricity are becoming more viable as the costs of panels drop and their efficiency improves. Wind power is being tested today, with promising experimental results from wind turbines mounted on cell towers [6]. Fuel cells have been in operation at some cell sites for years, long enough to have demonstrated a positive return on the investment. Hence, by deployment of energy initiatives, a tremendous shift in the energy demands for telecommunications services can be effected.

The amount of energy savings can be computed as a function of the percent of switch consolidation and the level of energy initiatives undertaken. Distributions of energy intensity as a function of the types of buildings involved are used in the calculations below.

Let:

\[ B(s, l, d) = \text{Distribution of building sizes } s \text{ at location } l \text{ with consolidation distribution } d \]

\[ E(s, l, i) = \text{Energy intensity of building sizes } s \text{ at location } l \text{ with energy initiative } i \]

\[ \sum \int \int B(s, l, d)E(s, l, i)ds dl = \text{Total energy consumption across all buildings and locations with consolidation distribution } d, \text{ summed over all energy initiatives } i \]

Figure 2 shows the results for a typical region with 50 million lines of telephone customers. It plots normalized energy consumption versus the switch consolidation distribution percentile with two different levels of energy initiatives deployed. It shows the normalized reduction in energy consumed. If nothing is done, power consumption remains at 100 percent compared to today’s usage. With deployment of energy initiatives, it is possible to obtain an 80 percent reduction in energy consumption.

These results portray the potential reduction in energy consumption, but they do not include the costs involved to implement these energy initiatives. A business case is developed to show the incremental energy savings that are achieved at each step along the way. The Bell Labs Telecom Power Estimator is used to evaluate the incremental decisions telecom
providers must make by performing a cost-effective business case analysis.

**Reducing Telecommunications Network Energy Consumption**

The unprecedented growth of bandwidth demand can easily cause telecommunications network operators’ energy consumption to rise in step with the growth. The resulting increase in electricity costs leads to reduced margins at a time when competition is also driving prices down. The network operator has two options when planning to reduce power consumption. First, there are new network architectures that are inherently more energy-efficient and which can simultaneously provide the flexibility to support continued increases in demand. Second, choices in network equipment, options, and support equipment for new or existing infrastructure can have a tremendous impact on the amount of power consumed. Both options are quite viable and should be part of any power reduction plan. These two concepts are introduced in the following sections.

**New Network Architectures Provide Improved Energy Efficiency**

Not only are science and technology helping to reduce equipment power consumption, but more efficient network architectures are emerging as well. These include the use of PON and RN systems in wireline networks and the simplification of base station functions in wireless networks. Extensive use of these architectures is possible because of migration to a server hierarchy whereby servers or controllers reside in a small number of central locations in a network to provide the intelligence for all sites downstream from the network core. These new network architectures feature less intelligent and often less power-hungry facilities residing away from the core. As a result, these remote sites are seldom staffed and are prime locations for considering energy reduction initiatives.

To illustrate the effect of moving toward a more centralized data network architecture, coupled with significant improvements in access technologies, refer to the example portrayed in Figure 3 [1]. The power usage of the 100,000-subscriber TDM CO example previously described is shown, along with the estimated reduction in power use for a next-generation network serving the same 100,000 subscribers. The next-generation network architecture provides services to the subscriber exclusively by PON systems that require only passive equipment in the outside plant (OSP). This PON ingress and egress equipment, located in the central office that used to house the TDM switch, consumes very little energy as compared to the legacy switch. Included in the next-generation

![Figure 2. Total energy consumption versus example energy initiatives.](image)
view is an allocated cost for the IP Multimedia Subsystem (IMS) network for the 100 K subscribers. The net effect is an impressive 85 percent reduction in power required.

While the specifics of energy usage differ significantly between wireline and wireless deployments, the high level architectural trends are very similar. Network intelligence and services are migrating toward a few serving sites (data centers) where application servers provide customer services through simpler aggregation and access networks. As a result, there are fewer staffed sites, and many of the distributed sites away from the core are candidates for energy efficiency options and even powering by eco-friendly sources.

Methodology for Planning Energy-Reducing Network Changes

The methodology for planning network changes to reduce energy usage consists of three cascading steps:

- **Energy consumption hierarchy.** Identification of the network elements that consume power and their location in the network.
- **Energy-saving chain.** Identification of network element dependencies upon each other’s power dissipation (e.g., larger air conditioning units having higher energy consumption are necessary if inefficient power rectifiers are installed because of the energy they waste through heat radiation). This allows network operators to target the most effective points for energy reduction by applying energy-saving initiatives.
- **Energy-saving initiatives or options.** Determination of specific choices or actions that can be taken to reduce energy consumption for one or more network elements (e.g., replacing low-efficiency rectifiers with high-efficiency rectifiers, which requires capital and installation expense, but these expenses may be offset in 12 to 15 months based on today’s high energy costs). Sets of initiatives are often deployed simultaneously due to typically lower installation costs as compared to deploying the initiatives one at a time.

**Energy consumption hierarchy.** The highest potential power savings are in access network locations for wireline and wireless networks simply because of the quantity of these locations as compared to the quantity of central or core nodes. Even relatively small power savings at an access node, multiplied by the total number of access nodes in a network, will typically result in significant energy savings overall. The energy consumption hierarchy for wireline and wireless access networks is presented in Table I and Table II, with network equipment located closest to the edge of the access network listed in the columns to
the left. This layout makes it easy to comprehend the larger multiplying factors closer to the edge of the network (left) as compared to moving closer toward the core (right). This view also makes it easy to see the power distribution requirements for various network architectures. Looking down the columns in Table I, for example, it is obvious that no network equipment is required at the customer premises for plain old telephone service (POTS), and that no network power is required in the outside plant for PON. Equipment and

Table I. Wireline access network energy consumption hierarchy.

<table>
<thead>
<tr>
<th>Subscriber type</th>
<th>Access network segment</th>
<th>Customer premises</th>
<th>Outside plant</th>
<th>Central office</th>
</tr>
</thead>
<tbody>
<tr>
<td>POTS</td>
<td>(Lifeline power)</td>
<td>Remote terminals</td>
<td></td>
<td>Switch</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Battery charging</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Rectifier</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cooling</td>
</tr>
<tr>
<td>DSL</td>
<td>DSL subscriber CPE</td>
<td></td>
<td>DSLAM</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>DSLAM</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Ethernet aggregator</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>DWDM</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>DC-DC converter</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Rectifier</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cooling</td>
</tr>
<tr>
<td>PON</td>
<td>PON subscriber CPE</td>
<td></td>
<td>N/A</td>
<td>PON system</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Ethernet aggregator</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>DWDM</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>DC-DC converter</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Rectifier</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cooling</td>
</tr>
<tr>
<td>AE</td>
<td>AE subscriber CPE</td>
<td></td>
<td>Ethernet switch</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Ethernet aggregator</td>
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<td></td>
<td></td>
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<td></td>
<td>DWDM</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>DC-DC converter</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Rectifier</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cooling</td>
</tr>
</tbody>
</table>

AE—Active Ethernet  
CPE—Customer premises equipment  
DC—Direct current  
DSL—Digital subscriber line  
DSLAM—Digital subscriber line access multiplexer  
DWDM—Dense wavelength division multiplexing  
PON—Passive optical network  
POTS—Plain old telephone service

Table II. Wireless access network energy consumption hierarchy.

<table>
<thead>
<tr>
<th>Access network segment</th>
<th>BTS</th>
<th>Backhaul</th>
<th>MSC</th>
</tr>
</thead>
<tbody>
<tr>
<td>End user equipment (cell phone, smart phone, or laptop with cell phone)</td>
<td>Radio equipment</td>
<td>E1/T1 or</td>
<td>Switch</td>
</tr>
<tr>
<td></td>
<td>Hut</td>
<td>Ethernet or</td>
<td>Battery charging</td>
</tr>
<tr>
<td></td>
<td>Battery charging</td>
<td>Fiber or</td>
<td>Rectifier</td>
</tr>
<tr>
<td></td>
<td>Rectifier</td>
<td>Microwave</td>
<td>Cooling</td>
</tr>
<tr>
<td></td>
<td>Cooling</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

BTS—Base transceiver station  
MSC—Mobile switching center
power requirement differences for each architecture are easily compared in the central office as well.

Energy-saving chain. The sequence of the network elements and the interaction between them results in energy consumption cascading dependencies (identified through the energy consumption hierarchy) [1, 4]. These dependencies can be identified and quantified by developing an energy-saving chain. Figure 4, for example, presents an energy savings chain for a wireless BTS. This BTS has four key energy-consuming elements:

- RF load (feeder: 120 Wh and antenna: 120 Wh),
- Radio equipment (signal processing: 2.135 kWh and RF power amplifier: 4 kWh),
- DC power system, and
- Cooling system.

The BTS initially requires an input energy of 10 kWh. Each key element consumes a certain portion of the total energy. For example, the cooling system consumes 2.5 kWh, about one third the power consumption of the other three elements combined.

When an energy-saving initiative is applied to reduce 1 Wh at the feeder, then the RF amplifier will yield a magnified savings of 16.7 Wh because 15.7 Wh was dissipated in the radio equipment to provide the additional 1 Wh at the feeder. Similar magnified savings result at the DC power system and cooling system. By combining the 1 Wh saving at RF load and 16.7 Wh saving at radio amplifier, the DC power system will yield additional savings of 3.1 Wh (assuming that the efficiency level of the DC power system is 85 percent). Now, the top three elements have yielded a savings of 20.8 Wh (1 Wh + 16.7 Wh + 3.1 Wh). Consequently, a savings of 6.9 Wh at the cooling system results from the energy reduction of the top three elements. Finally, we conclude that a 1 Wh saving at the feeder can result in a 27.7 Wh (20.8 Wh + 6.9 Wh) total savings at the BTS level. The cascading effect is about 28 times and is highest when an energy-saving initiative is implemented closer to the load furthest upstream (as illustrated above).

**Energy-saving initiatives.** Once the energy consumption hierarchy and energy-saving chain are analyzed, a network operator is ready to begin identifying the most appropriate energy-saving initiatives. This section introduces initiatives or options that have significant

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<table>
<thead>
<tr>
<th><strong>Figure 4.</strong></th>
<th><strong>BTS energy-saving chain (read right-to-left).</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AC power</strong></td>
<td><strong>BTS</strong>—Base transceiver station</td>
</tr>
<tr>
<td>10 kWh</td>
<td><strong>DC</strong>—Direct current</td>
</tr>
<tr>
<td><strong>TOTAL:</strong></td>
<td><strong>RF</strong>—Radio frequency</td>
</tr>
<tr>
<td>27.7 Wh saving</td>
<td></td>
</tr>
<tr>
<td>3. Links 1 &amp; 2 yield 3.1 Wh savings in DC power system</td>
<td></td>
</tr>
<tr>
<td>2. Link 1 yields 16.7 Wh savings in RF amplifier</td>
<td></td>
</tr>
<tr>
<td>1. First save 1.0 Wh in feeder</td>
<td></td>
</tr>
<tr>
<td><strong>Link 4</strong></td>
<td><strong>Cooling system</strong></td>
</tr>
<tr>
<td>2.5 kWh</td>
<td></td>
</tr>
<tr>
<td><strong>Link 3</strong></td>
<td><strong>DC power system</strong></td>
</tr>
<tr>
<td>1.125 kWh</td>
<td></td>
</tr>
<tr>
<td><strong>Link 2</strong></td>
<td><strong>Radio equipment</strong></td>
</tr>
<tr>
<td>6.135 kWh (signaling processing and RF amplifier)</td>
<td></td>
</tr>
<tr>
<td><strong>Link 1</strong></td>
<td><strong>RF load</strong></td>
</tr>
<tr>
<td>240 Wh (feeder and antenna)</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>AC</strong>—Alternating current</th>
<th><strong>BTS</strong>—Base transceiver station</th>
<th><strong>DC</strong>—Direct current</th>
<th><strong>RF</strong>—Radio frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. First save 1.0 Wh in feeder</strong></td>
<td></td>
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<tr>
<td><strong>2. Link 1 yields 16.7 Wh savings in RF amplifier</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>3. Links 1 &amp; 2 yield 3.1 Wh savings in DC power system</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>4. Links 1, 2, &amp; 3 yield 6.9 Wh savings in cooling system</strong></td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>AC</strong>—Alternating current</th>
<th><strong>BTS</strong>—Base transceiver station</th>
<th><strong>DC</strong>—Direct current</th>
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</tr>
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<tbody>
<tr>
<td><strong>TOTAL:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>27.7 Wh saving</strong></td>
<td></td>
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</tr>
</tbody>
</table>

**AC**—Alternating current  
**BTS**—Base transceiver station  
**DC**—Direct current  
**RF**—Radio frequency
energy-saving potential in wireline and/or wireless access networks. With an appropriate combination and implementation of initiatives, wireline and wireless networks, respectively, can achieve an energy reduction of 40 percent and 60 percent or more [4]. The implementation priority, deployment timing, and return on investment (ROI) of each initiative can be thoroughly analyzed and planned by using the Bell Labs Telecom Power Estimator.

Figure 5 provides a comprehensive list of initiatives for wireline and wireless access networks. For wireline networks, four categories of initiatives can be planned and developed:

- **Building power distribution.** Implement high-efficiency rectifiers, uninterruptable power supply (UPS), and distributed power supplies.
- **Cooling system.** Implement high-efficiency equipment, higher thermostat set points, reduced duty cycle, and/or geothermal or fresh-air cooling.
- **Sustainable power.** Install hybrid (grid-assist) wind and/or solar power systems or fuel cells. Geothermal cooling may also be considered in this category.
- **Switch line consolidation.** Powering-down, removing, and decommissioning unused line circuit packs and other equipment. This item is high on the energy-saving chain, above power rectifiers and cooling equipment.

Due to a low fill rate and ongoing trimming of operational expenditures (OPEX), switch line consolidation is a “by-default” initiative for many network operators, meaning the business case tends to be so compelling (in terms of months to pay back implementation costs), it almost always makes sense to implement. The fact that little capital expenditure (CAPEX) is required to implement this initiative also makes it particularly attractive.

Wireless network initiatives should be developed separately for brownfield and greenfield scenarios because different business case parameters normally apply. The following energy-saving initiatives are applicable to brownfield wireless networks:

- **Radio standby-mode upgrades.** Installing upgrades to power-down carriers and baseband equipment when they are under-utilized (particularly overnight). This initiative is normally available through software and sometimes hardware upgrades.
- **Natural (fresh-air) or geothermal cooling.** Implementing free ventilation, forced fan cooling, or heat exchangers. Minimizes or eliminates the need for inefficient air conditioning systems.
- **Advanced thermostat control.** Upgrading thermostats to trigger operation of cooling equipment at a higher temperature and allow a higher fluctuation of the low-high temperature control range to reduce cooling system power consumption.
- **DC system eco-mode.** Installing an advanced power system controller scheme to ensure rectifiers operate at peak efficiency in virtually all conditions.
- **High-efficiency rectifiers.** Replacing low-efficiency rectifiers with high-efficiency units.
- **Power monitoring and control.** Installing an intelligent power monitoring and management system to achieve better usage of power over an entire building or focus area.
- **Sustainable power.** Installing hybrid (grid-assist) wind and/or solar power systems and/or fuel cells.

Greenfield wireless networks have a similar set of initiatives; however, each initiative can have multiple options. For example, the rectifier option is a rectifier initiative with options of low efficiency and high efficiency. A selection of a specific option of each initiative should be carefully evaluated based on the total cost of ownership that is enabled by using the Bell Labs Telecom Power Estimator.

### Evaluating the Potential of Alternative Energy Sources for Telecommunications

Higher costs for grid power, lower costs for sustainable energy options, improving technologies, government incentives, and increased consumer demand for eco-friendly products and services are combining to make a compelling argument for change within the industry. While sustainable power options can provide savings in many applications as a standalone
Figure 5.
Energy-saving initiatives for wireline and wireless access networks.
investment, coupling energy-savings initiatives with sustainable power options can further improve the cost effectiveness of the business case. This section presents an overview of sustainable energy options and describes scenarios that are potentially viable for their use in telecommunications networks.

Numerous eco-friendly energy sources are available, including wind, solar, and the purchase of green power, but it is not simple to determine the most viable options, if indeed any are viable. Not only must the total power requirement of the facility be considered, but also the local cost of electricity and the viability of the different eco-friendly options. Therefore, one must consider and analyze the various data for each option and regional variation. Some of the sources of data used in the evaluations performed by the Bell Labs Power Estimator are discussed.

**Data Sources and Options for Eco-Friendly Power**

Telecommunications operations, like many industries, are distributed across regions of interest. Potential alternative energy sources for use by telecom equipment, as well as the heating or cooling of telecom facilities, must consider the full diverse range of alternative energy sources available at the national level. It also means fully considering the use of energy in current operations and facilities. Without access to specific data on energy use by telecommunications infrastructures, aggregate level data may be used to estimate current impacts. Data for the analysis is indispensable for energy usage estimations. Local and regional datasets may also be used to give a baseline validation to evaluate the cost effectiveness of pursuing renewable resources. Regional data sources can include:

- Fuel mix for electricity generation,
- Heating degree days (HDD) and cooling degree days (CDD),
- Renewable energy availability, and
- Energy usage by building type.

One of the main electricity sinks within buildings is the climate control system. It takes a significant amount of energy to maintain a near constant internal building temperature during the winter and summer months. This energy consumption varies for different facilities due to climatic variations associated with different geographic locales. The appropriate units of measure here are heating degree days and cooling degree days. In short, these are metrics that describe how many “degrees” of heat or cooling are needed to keep the facility operating in a comfortable range. Fortunately, statistics about heating and cooling degree days are available by postal code. Annual total heating and cooling degree days provide a quick way to see how much the daily temperature differs from 65°F (18°C), summed for the entire year. The distribution of heating and cooling degree days defines in which climate zone a facility is located, as shown in Table III.

By linking heating and cooling degree days to each facility by location, one can determine each facility’s climate zone. For example, in the United States, the Commercial Building Energy Consumption Survey (CBECS) database has data for the average energy usage per square foot by primary use and climate zone. This allows for conversion between square footage and electricity usage. Furthermore, the U.S. Environmental Protection Agency’s eGRID database contains information on electricity carbon intensity (and other air emissions) by location. This enables the conversion between facility electricity usage and estimated carbon emissions. Similar information is available for most developed countries.

**Renewable resource availability.** Local and regional data can be used to give a first-order estimation of renewable energy availability. Weather information is also a key factor. Records of average solar intensities and wind speeds are good indicators of how efficient an array of solar cells or a turbine would be at generating renewable energy. A visual distribution of these averages across the United States and Europe can be seen in Figure 6 and Figure 7, respectively.
Correlating the potential for solar and wind availability with facility location provides an insight as to which facilities may benefit most from available solar or wind renewable opportunities. While this is not indicative of facilities’ carbon footprints, it is an important piece of information to assess possible mitigation strategies.

**Wind power generation.** Electric power generated from wind resources is a cubic function of the wind velocity. Thus each additional unit of wind adds
greatly to its value for generating power. For example, in the U.S., wind data was provided at a resolution of 1% latitude by 1% longitude from the Atmospheric Science Data Center. Wind strength is reported in seven power classes, 1 through 7, based on the average wind speed for the year, measured 10 meters from ground level. Power class 7, which is found in remote and high-altitude areas, is highly unlikely for telecom central office locations and is therefore excluded from this analysis. Conversion of the power class into an actual number for the density of wind power and speed was made according to figures posted by the American Wind Energy Association, as shown in Table IV.

In general, large-scale wind farms prefer locations with wind classes of 4 or better, which maximize the cost-effectiveness of generating power using wind. On a small scale, a 22 foot, 10 kW wind turbine installed at a power class 4 telecom base station facility can likely generate about 11,000 kWh of electricity annually, potentially 25 percent of its total annual energy requirement.

**Solar power generation.** Specifically, for the U.S., the solar intensity data was measured at numerous stations. Relative solar resource intensities range, on average, between 2.2 and 6.8 kWh/m²/day based on figures posted by the National Renewable Energy Laboratory. All postal codes were matched to the nearest station, and facilities were subsequently matched to solar intensity values by their postal codes. Facilities were also matched to their electricity prices by state, using data from the Energy Information Association. Multiplying these two numbers together provides potential savings to a facility in dollars per day per square meter. This number was multiplied by 365.25 to change the units to savings per year and additionally multiplied by 10 percent as an efficiency factor that reflects the current state of photovoltaic technology. In general, solar power may look attractive with solar intensities greater than 4 kWh/m²/day when the electric grid prices are approximately $0.12/kWh or higher. For example, a 300 square meter photovoltaic panel array deployed at a New York base station facility could generate approximately 14,000 kWh of electricity annually, potentially 30 percent of its total annual energy requirement.

**Green power.** In addition to wind and solar power, green grid power is also an option for eco-friendly energy for telecom infrastructure that has regional variations. Green power is commonly referred to as the portion of the electricity grid mix generated from renewable resources. Since, in the U.S., for example, electricity is generated by different mixes of technologies in each state, it is not surprising that the availability to purchase green power varies. The U.S. Department of Energy has a database of state incentives for renewable energy and efficiency, which outlines each state’s specific renewable energy portfolio standards. All 50 states have some type of overall renewable standard, ranging from 10 percent to 25 percent, for their electricity grid mixes.

### Hybrid Renewable Energy Sources: Wind and Solar Power

As stated previously, a relatively small-scale, 22 foot, 10 kW wind turbine installed at a telecom facility in a class 4 wind area can likely generate about 11,000 kWh of electricity annually. Wind turbines never run at full capacity for an entire year. Instead, nearly all wind power facilities produce between 20 percent and 40 percent of the energy that would be possible if the wind blew at the average power densities. Therefore, all power density numbers were multiplied by a factor of 0.3, which is generally the assumed capacity factor for wind turbines. The power densities are reduced further to account for the mechanical parts of a wind turbine by multiplying this result by an efficiency factor of 0.85. These numbers can be used to estimate the potential for wind power

<table>
<thead>
<tr>
<th>Power class density (W/m²)</th>
<th>Speed (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;100</td>
<td>&lt;4.4</td>
</tr>
<tr>
<td>100–150</td>
<td>4.4–5.1</td>
</tr>
<tr>
<td>150–200</td>
<td>5.1–5.6</td>
</tr>
<tr>
<td>200–250</td>
<td>5.6–6.0</td>
</tr>
<tr>
<td>250–300</td>
<td>6.0–6.4</td>
</tr>
<tr>
<td>300–350</td>
<td>6.4–7.0</td>
</tr>
</tbody>
</table>

**Table IV. Table of wind power class to power density conversion rates.**
on central office buildings. Assuming the average price of turbines ($415 per square meter), the central office facilities are separated into several groups: those with payback periods of less than seven years (our candidate set of central offices) and those with payback periods greater than seven years. The distribution of central offices that potentially could leverage the use of wind energy is shown in Figure 8.

In a similar way, central office facilities were characterized by the feasibility of driving cost savings by using solar-generating technologies. This calculation was done by assuming a cost of $1,400 per square meter of solar panel. Using these values, central office facilities were identified that would recover initial capital expenses in seven years or less. The distribution of central office facilities with potential for solar energy usage is also given in Figure 8.

**The Bell Labs Telecom Power Estimator for Improving Sustainability**

Numerous energy-saving initiatives and eco-friendly alternative power options have been discussed in the preceding sections. Many of the conclusions cited are based on analyses performed by the Bell Labs Telecom Power Estimator, described in this section.

**Overview of the Bell Labs Telecom Power Estimator**

Choosing the appropriate energy-saving options and alternative energy options to implement is a non-trivial task. Factors affecting the decision include whether the subject network is existing or new, and whether it is wireline or wireless, as well as the network technology deployed, the timeframe for deployment of the next-generation technology, growth rates, age of network, cost of power, cooling days, sunny days, sun angle, wind speed and profile, geographic location, government incentives, and consumer sentiment. An easy way was needed to identify likely areas within a network operator’s network where a compelling eco- and business case for improving sustainability might exist. This need led to the development of the Bell Labs Telecom Power Estimator. The TPE is used to demonstrate the economic benefits for implementing sustainability options to planning personnel, allowing them to identify portions of their network where a detailed engineering analysis may be appropriate. The domains of the TPE are the central office and access portions of wireline and wireless networks that typically dominate power consumption in the networks. Further, the TPE is intended to be used (as its name implies) to generate “estimates” of likely system cost and performance rather than specific calculations, to aid in prioritizing sites for more detailed screening and scoping analyses.

The TPE operates by taking a minimal set of inputs (location, area served, age of network, number of subscribers, services offered, and growth rates) and performing an actual bottom-up network design to meet the calculated traffic demands. This network design serves as a representation of the actual

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**Figure 8.**

*Distribution of central offices’ solar and wind generation potential.*
The Bell Labs Telecom Power Estimator is a powerful tool to simplify the analyses that must be performed when planning network-wide energy reduction initiatives or alternative power supply solutions to reduce the ecological impact. To summarize TPE capabilities, the tool:

- Requires minimal user input, relying on internal geographic databases for populations, demographics, heating/cooling degree days, solar intensity, wind class, grid power sources and costs, and equipment power consumption.
- Provides planning results for wireline and wireless access networks, both greenfield and brownfield options.
- Analyzes energy-saving initiatives, alternative energy options, or both for access in a particular network or region.
- Develops a high-level business case useful for identifying locations where energy-saving initiatives or alternative energy options are most viable.
- Analyzes greenhouse gas reduction realized with implementation of the network efficiencies identified.

**Developing the Business Case for Energy Reduction Initiatives**

The Telecom Power Estimator develops a five-year business case for energy reduction initiatives. The example in Figure 10 provides sufficient detail, for instance, to break out a specific estimate for rectifier power consumption based on rectifier efficiencies that are determined from the general user inputs. When an energy-saving initiative is applied, the tool will estimate both the costs and savings for the initiative and develop the business case. Each energy-saving initiative has a representative cost model based on actual costs (CAPEX and OPEX). An example of the savings and a business case summary for this initiative are shown in Figure 10. Note that this example shows a positive business case with less than two year...
payback for the high efficiency rectifier initiative based on power savings alone.

Often individual initiatives may have a negative business case. Sometimes the combination of several initiatives may provide a better business case than if each initiative were considered separately. One of the strengths of the TPE is that it allows analysis of multiple energy-saving initiatives simultaneously and develops the business case for the combined analysis. Energy credits that may be available for particular geographic locations are also considered in the business case based on database information or additional user input.

Energy credits are sometimes available based on the reduction of the carbon footprint for a particular location. The TPE provides an estimate of the reduction in carbon footprint as shown in Table V. This data may also be useful for network operator marketing teams if customers in their serving area have shown a preference for eco-friendly products and services.

**Alternative energy options to improve sustainability.** Alternative energy options are also evaluated by the Telecom Power Estimator. The geographic location, power estimates resulting from the implementation of the selected energy-saving initiatives, and the extensive database of geographically based alternative energy data are used to determine the viability of each alternative energy option and develop a business case showing the return on investment. Reductions in grid power usage as well as greenhouse gas footprint are clearly quantified in the results.

The following alternative energy options are analyzed:

- Use of solar power, wind power, or both, for both grid-assist and off-grid scenarios,
- Options for backup power (diesel generation or fuel cell),
- Use of a hybrid power controller to optimize utilization of all power sources available at a site.

---

Figure 9. Exemplary power use display of the Telecom Power Estimator for POTS network access.
<table>
<thead>
<tr>
<th>Year</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total yearly KWHr reduction</td>
<td>22,156,405</td>
<td>22,156,405</td>
<td>22,156,405</td>
<td>22,156,405</td>
<td>22,156,405</td>
</tr>
<tr>
<td>% energy usage saved</td>
<td>21%</td>
<td>21%</td>
<td>21%</td>
<td>21%</td>
<td>21%</td>
</tr>
<tr>
<td>TOTAL yearly energy COST SAVINGS</td>
<td>€2,437,205</td>
<td>€2,437,205</td>
<td>€2,437,205</td>
<td>€2,437,205</td>
<td>€2,437,205</td>
</tr>
<tr>
<td>TOTAL yearly initiatives costs</td>
<td>€6,381,284</td>
<td>€0</td>
<td>€0</td>
<td>€0</td>
<td>€0</td>
</tr>
<tr>
<td>Switch line consolidation</td>
<td>€0</td>
<td>€0</td>
<td>€0</td>
<td>€0</td>
<td>€0</td>
</tr>
<tr>
<td>High efficiency rectifiers</td>
<td>€6,381,284</td>
<td>€0</td>
<td>€0</td>
<td>€0</td>
<td>€0</td>
</tr>
<tr>
<td>Wireless BTS sleep mode</td>
<td>€0</td>
<td>€0</td>
<td>€0</td>
<td>€0</td>
<td>€0</td>
</tr>
<tr>
<td>Wireless high efficiency PA</td>
<td>€0</td>
<td>€0</td>
<td>€0</td>
<td>€0</td>
<td>€0</td>
</tr>
<tr>
<td>Remoting radio heads</td>
<td>€0</td>
<td>€0</td>
<td>€0</td>
<td>€0</td>
<td>€0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cum. discounted cash flows-cost</td>
<td>€6,381,284</td>
<td>€6,381,284</td>
<td>€6,381,284</td>
<td>€6,381,284</td>
<td>€6,381,284</td>
</tr>
<tr>
<td>Cum. discounted cash flows-savings</td>
<td>€2,176,075</td>
<td>€4,119,000</td>
<td>€5,853,754</td>
<td>€7,402,642</td>
<td>€8,785,577</td>
</tr>
<tr>
<td>CDCF (end of year)</td>
<td>− €4,205,209</td>
<td>− €2,262,284</td>
<td>− €527,530</td>
<td>€1,021,357</td>
<td>€2,404,292</td>
</tr>
<tr>
<td>Total cash flow</td>
<td>− €3,944,080</td>
<td>€2,437,205</td>
<td>€2,437,205</td>
<td>€2,437,205</td>
<td>€2,437,205</td>
</tr>
<tr>
<td>Discounted payback period (years)</td>
<td>3.34</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IROR</td>
<td>49.4%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 10.**
Energy-saving initiative analysis and business case.
The economic costs and benefits associated with alternative power technologies should also be considered when planning for reductions in the energy use and environmental impact of telecommunications networks. This requires consideration of the capital costs of using the renewable energy source (e.g., building small wind turbines or solar panel arrays), the local cost of fuels or electricity, the grid emissions of the electricity, and energy technology lifetimes.

There is potential for telecommunications network operators to combine both power usage reductions that are readily available followed by adding, on a selected basis, alternative energy supply options. While it may not always be practical from a business case perspective to perform both activities together at the same site, for the cases where the business plan permits, the combined effect at any one site can be very compelling. The approach of first reducing a site’s overall power requirements, and then, where warranted based on location, designing and installing energy supply options may be practical in locations where otherwise they would not be practical without first performing the power usage reductions.

Financial incentives for alternative energy usage. An important consideration for these options is the availability of governmental alternative energy generation subsidies or tax credits available for projects—investment tax credits (ITCs) and production tax credits (PTCs). ITCs provide incentives for purchasing (investing in) the technology, while PTCs require energy to be generated. As a specific example, given significant wind availability, a network operator might be able to receive an ITC of 25 percent of the cost of buying a wind turbine or might receive a one to two cent per kilowatt-hour (approximately 10 percent to 20 percent) credit as energy is generated. Given the potential for wasting subsidies, many credits are PTCs rather than ITCs, to ensure that projects are sufficiently valuable to the owner that energy can economically be generated. The difference in the tax credits could have substantial effect on the economic performance of a system.

PTCs and ITCs may be available at various governmental levels (i.e., owners might be able to receive multiple credits from different sources). For example, in the U.S., wind, solar, and geothermal PTC credits are $0.021 per kWh. These credits typically last five or ten years from the in-service date.

Inevitably, the most important calculations are the comparisons between the current cost of electricity being paid to the local utility and any potential valuations of environmental effects like carbon dioxide emissions.

Off-grid alternative power scenario. Figure 11 presents an output from the Telecom Power Estimator displaying costs and savings for an off-grid wireless cell site that is initially powered by a diesel generator. The PMO power costs are for the fuel cost and transportation to the site. The future method of operation (FMO) solution is the installation of a combination of solar and wind alternative generation as well as additional storage batteries to allow for capturing peak wind/solar power generation that exceeds usage requirements. Coupling these with a smart power controller that monitors available non-generator sources allows for optimum usage of all sources, running the diesel generator set only when necessary. With such an arrangement it is possible to reduce generator

<table>
<thead>
<tr>
<th>Carbon footprint—metric tons of carbon dioxide per year</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>PMO (present method of operation)</td>
<td>94,834</td>
<td>94,834</td>
<td>94,834</td>
<td>94,834</td>
<td>94,834</td>
</tr>
<tr>
<td>FMO (future method of operation)</td>
<td>75,252</td>
<td>75,252</td>
<td>75,252</td>
<td>75,252</td>
<td>75,252</td>
</tr>
<tr>
<td>Change</td>
<td>−19,583</td>
<td>−19,583</td>
<td>−19,583</td>
<td>−19,583</td>
<td>−19,583</td>
</tr>
<tr>
<td>CO₂ reduction</td>
<td>21%</td>
<td>21%</td>
<td>21%</td>
<td>21%</td>
<td>21%</td>
</tr>
</tbody>
</table>

Table V. Greenhouse gas savings resulting from energy-saving initiatives.

FMO—Future method of operation
PMO—Present method of operation
use to 30 percent of the time required in the PMO case.

Figure 11 also shows the business case cumulative distributed cash flow (CDCF) that results from this sustainable energy optimization. The business analysis is quite compelling, with a two year payback for sites requiring off-grid power and with diesel costs in excess of $2 per liter, delivered.

The Bell Labs Telecom Power Estimator is modular, allowing additional energy-saving initiatives and alternative power options to be added easily. Capabilities of the TPE are continually being expanded.

Conclusions

Planning an efficient, eco-sustainable telecommunications network while meeting corporate financial and business goals is a challenging problem. While networks are naturally evolving to become more efficient, this takes years to occur. With the current high energy costs and government and consumer interest in greener technology, proactively reducing energy consumption and adding alternative, eco-friendly power sources often result in a better business plan, both short term and long term. Deciding on specific energy reduction initiatives and determining the viability of alternative power options that meet network operator business goals require a complex, multidimensional analysis. The Bell Labs Telecom Power Estimator helps network operators work through the maze of conflicting requirements and options to identify eco-friendly solutions that meet the financial and business goals while reducing the ecological impacts.

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process, and was an editor of a book on survivable net-
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