Automating a Building's Carbon Management

Geetha Thiagarajan, Venkatesh Sarangan, Ramasubramanian Suriyanarayanan, and Pragathichitra Sethuraman
TCS Innovation Laboratories, Chennai

Anand Sivasubramaniam
Pennsylvania State University

Avinash Yegyanarayanan
Tata Consultancy Services, Chennai

Buildings are the largest contributor to the world's carbon footprint, yet many building managers use only periodic audits to adjust resource consumption and carbon emission levels. The ECView framework leverages existing workflow systems to continually assess a building's carbon emissions in relation to daily weather, commuting and travel patterns, and changing government regulations.

The world is becoming increasingly more vigilant about energy use, and decision makers involved in resource allocation must consider environmentally beneficial, or *green*, solutions in managing systems. Energy consumption and carbon emissions are the two main concerns, and although the carbon footprint has several components, buildings appear to be the worst offenders in both categories. According to the US Green Building Council (www.usgbc.org), buildings account for nearly 72 percent of the US's electricity consumption and 39 percent of its carbon emissions.[1]

To determine a building's environmental impact and reduce its carbon footprint, managers must closely monitor the building's chief carbon contributors. At present, such monitoring consists of scheduling occasional audits to assess a building's resource consumption and emission levels and then basing any recommendations on the operational snapshot.

We believe this approach has serious deficiencies. A building's carbon footprint is the product of complex interplay among the building's structural and infrastructure characteristics, business processes and operational patterns, climate and weather dynamics, energy sources, workforce commute patterns, and government regulations. Because these disparate factors can change daily, any recommendation based on a snapshot will rapidly become invalid. A more effective approach is to continually track these influential factors and tune subsequent recommendations using a realistic portrait of energy use and carbon emissions.

When done manually, continual monitoring can be tedious, error-prone, and expensive, so it makes sense to use information technology (IT) for carbon management. Green solutions built around IT not only scale with building size, but they also keep pace with a building's operational dynamics. In addition, IT offers a way to encapsulate and repeat best practices in creating and applying green solutions, so even facilities with less experienced personnel can reap the benefits of expert carbon management. Finally, because IT has already permeated systems that contribute to an enterprise's carbon footprint, such as enterprise resource planning and workflow systems, those developing an IT system for carbon footprint management need not start from scratch. IT has a firm foundation in standardizing and securing distributed networked systems, which can be beneficial in building management.[2]

Recognizing the power of IT to facilitate carbon management, we developed ECView (Energy and Carbon View), an

 Published by the IEEE Computer Society

IT framework that assists managers in finding and maintaining solutions that reduce a building's carbon footprint. To test ECView's capabilities, we used it to continuously monitor and analyze the carbon footprint of a Tata Consultancy Services (TCS) office building in India over the course of a year. Using the insights our framework offered, we identified ways to reduce the TCS building's carbon footprint. Some of these strategies require zero capital expenditure.

FRAMEWORK FEATURES

ECView provides real-time carbon tracking, accounting, and asset management, and it supports a feature set that enables insights beyond what simple meter readings can provide.

Carbon tracking

ECView aims to transform building carbon management from periodic sampling to a real-time process that the facility manager can monitor and execute continuously. ECView starts by collecting data from sources such as building management and ERP systems and then applies analytic engines to process the data in role-based dashboards that facilitate a variety of insights valuable to decision makers. Each diverse functional unit—finance, sustainability, or facilities—has a different dashboard that contains real-time views of the data most relevant to that unit. ECView also generates curves that prioritize viable carbon abatement projects according to a metric the user chooses.

Asset management

To effectively manage a building's carbon emissions, an IT framework should track the health and performance of key infrastructure assets related to both the supply and demand sides of energy consumption. ECView performs all the required asset-keeping activities, such as benchmarking and tracking parameters related to the assets throughout their life cycle. In addition to these baseline functions, ECView can log the operational hours, outage durations, and maintenance history of key assets, as well as automatically raise alarms for scheduled preventive maintenance or expected forced outages and trigger appropriate workflows.

Multilevel monitoring support

Any IT solution should move beyond meters, integrating data from various sources and presenting it in a holistic fashion. The goal should be to provide managers with enough insight on carbon footprint contributors to make operational decisions that are more beneficial to the environment. The insights offered and analyses supported should not be determined solely by the amount of available instrumentation, and the system should be able to work around erroneous human inputs and faulty meter readings.

Two important characteristics of ECView differentiate it from traditional carbon management tools. First, the extent of analysis that traditional tools can support is closely tied to the available metering. In ECView, this dependency is minimal because the framework can support varying levels of facility metering through its internal analytical models. Second, ECView can analyze the carbon footprint at three different levels: resource, activity, and business process, leveraging the activity-based costing model[3] to apportion the resource-level carbon footprint to activities and business processes.

EMISSION MONITORING WITH METERS

The TCS building in our case study has a built-up area of 250,000 sq. ft. spread across five floors. It houses two departments, Infrastructure Services (IS) and Business Process Outsourcing (BPO), with roughly 3,000 cubicles, two datacenters (one for each department), and a cafeteria. The facility's peak energy demand is 3,000 kVA, and its average electricity consumption is roughly 1,012 MWh per month. An electric utility serves the facility; four in-house diesel generators, each rated at 1010 kVA, serve as backup.

To effectively manage a building's carbon emissions, an IT framework should track the health and performance of key infrastructure assets related to both the supply and demand sides of energy consumption.

We monitored the three commonly accepted categories of carbon emissions, as specified in the *Greenhouse Gas Protocol on Corporate Accounting and Reporting Standards 2004,* (GHG protocol; www.ghgprotocol.org):

- *Scope 1.* Emissions from activities that a building controls directly, including emissions from in-house fuel combustion, refrigerant leakage, and fire extinguishers.
- *Scope 2.* Emissions from the utility company's generation of the electricity that a building consumes.
- *Scope 3.* Emissions from wastes, water, employee commuting, and business travel.

As these categories show, the carbon footprint has complex components that stem from both the building

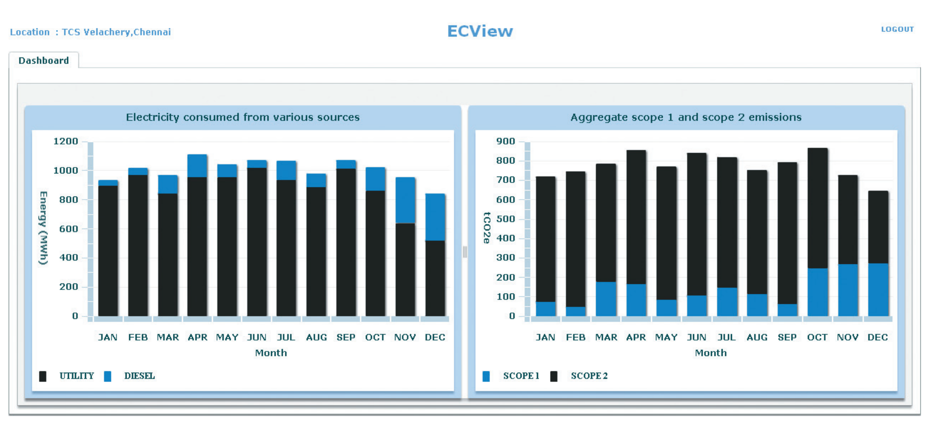

Figure 1. Monthly electricity consumption and aggregate Scope 1 and 2 emissions for the TCS building. In the second graph, Scope 1 and 2 emissions are measured in tonnes of carbon-dioxide equivalent (TCO2e).

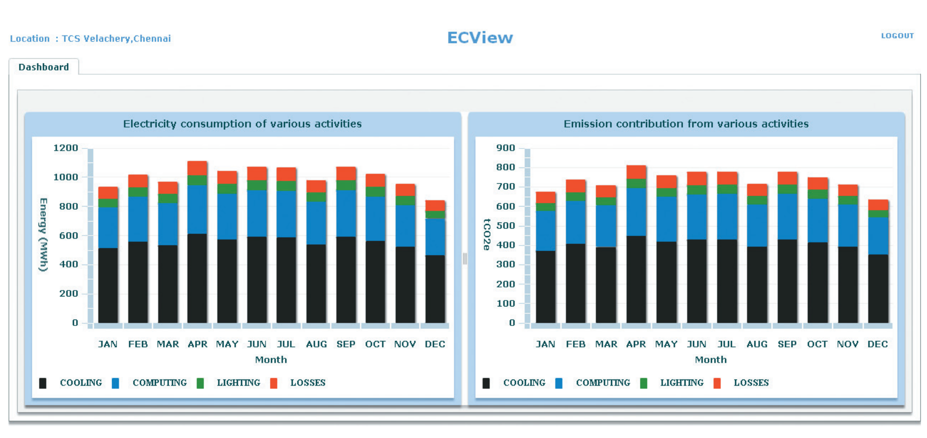

Figure 2. Electricity consumption and carbon footprint by activity for the TCS building. The consumption breakdown is based on data from activity meters, but ECView can estimate consumption by activity even without such meters. Clearly, cooling is the most significant contributor, in large part because of India's climate. Losses refer to energy leaks and waste within the power distribution network.

activities directly and from activities such as work-related travel, which contributes to carbon emissions indirectly from the vehicles used for commuting and business travel.

Our case study considered these three categories, focusing on emissions from in-house power plants, grid electricity consumption, and business travel and employee commuting—sources that cumulatively account for more than 95 percent of a service-sector office building's carbon footprint. In-house power plants (such as diesel generators) and grid electricity impact a building's energy bills, so they are interesting to track from a monetary cost perspective as well.

Scope 1 and 2 emissions

To track Scope 1 and Scope 2 emissions, ECView starts with readings from meters that individually track the electricity that the plant consumes from the utility company and in-house diesel generators. From this data and localized emission factors that are based on the utility's source mix, ECView arrives at the carbon footprint. A utility company can generate power from a mix of sources, including thermal, hydroelectric, nuclear, wind, and solar power. Each source emits different amounts of carbon during electricity generation; hence it is important to consider the utility company's source mix.

Figure 1 shows the TCS building's monthly consumption and aggregate Scope 1 and 2 emissions during the monitoring year.

ECView revealed that the facility sources around 87 percent of its electricity from the utility company and 13 percent from diesel generators. Of all the Scope 1 and 2 emissions, about 81 percent come from the utility company; 14 percent come from the diesel generators, and the remaining 5 percent come from liquified petroleum gas consumption (for cafeteria cooking) and refrigerant leakages (from chillers). Diesel consumption increases notably beginning in the tenth month of the study because, in that month, the utility company's regulations changed to prohibit industrial customers from drawing power between 6:00 pm and 10:00 pm. During such times, the facility met its electricity needs through the diesel generators, as evidenced by corresponding diesel consumption upswings.

Although knowing the facility's consumption at the resource level gave us a good idea about Scope 1 and 2 emissions, we still had several questions that resource-level monitoring could not answer: Which building activity consumes the most electricity? How much does each business unit contribute toward the building's carbon footprint? What measures can offer the highest footprint reduction for the investment?

To explore the answers to these questions, we used ECView to monitor the TCS building's consumption at a finer granularity. The building has meters that individually track the electricity that various activities consume, such as lighting, computing, and cooling. We fed readings from these activity-level meters into ECView, which then gave us an activity-oriented breakdown of the facility's electricity consumption and footprint.

As Figure 2 shows, cooling is the largest contributor, consuming 55 percent of the total electricity. This finding is understandable, given that the building is located in a tropical climate that is largely hot and humid. Computing and lighting consume 30 and 6.1 percent, respectively, and losses from equipment, distribution, and operations account for 8.7 percent.

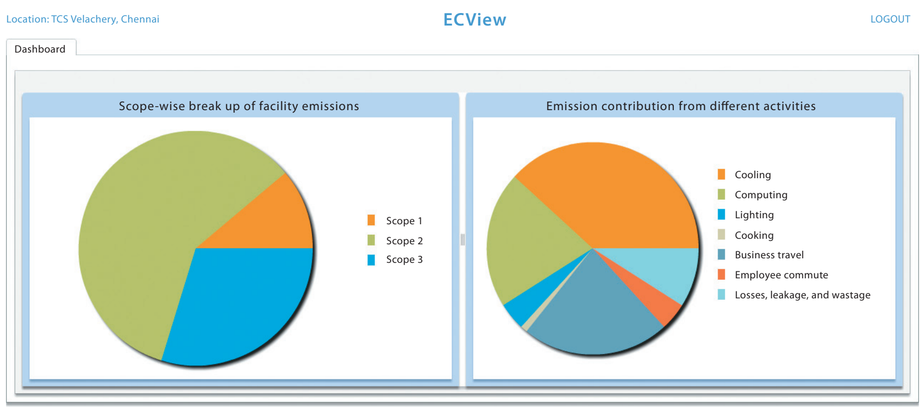

Figure 3. Carbon emission breakdown across emission type and activity. Travel was a significant contributor, although daily commuting was less influential, in part because employees tend to use public transportation and fuel-efficient motorcycles.

Scope 3 emissions

According to the GHG protocol, the primary contributors for Scope 3 emissions in a service sector office building are business travel and daily commutes made by the employees. Typically, business travel requests are raised, approved, and reimbursed in an organization through enterprise workflow systems. As soon as the business travel workflow is completed, data pertaining to the travel is automatically extracted and sent to ECView. Employee commute data is collected through a Web-based questionnaire integrated with ECView.

Figure 3 shows the breakdown of the facility's overall annual carbon footprint across activities. We gained several insights from these results. One is, again, that cooling is the most significant footprint contributor. Another is that, despite the GHG protocol's recommendations, reporting Scope 3 emissions should *not* be optional, particularly for service sectors. As Figure 3 shows, business travel was a significant contributor. Although daily commuting did not contribute that much to the footprint, this finding might be specific to the TCS building, where employees mainly commute using public transportation and motorcycles with a 140-mpg fuel efficiency. The commuting scenario could be quite different in other locations.

TRACKING PER-ACTIVITY CONSUMPTION WITHOUT METERS

A typical service-sector office building consumes electricity for lighting, computing, and cooling, but not all buildings have meters that track electricity consumption for each activity individually. For these buildings, ECView estimates the energy consumed from various sources that relate to the activity. For lighting consumption, it uses the building design's watts-per-square-foot value, the design deviation factor, and the building's lighting operational pattern. For computing consumption, it uses desktop or server specifications, personnel count, utilization percentage, and operational patterns. Finally, for cooling consumption, it uses heat-gain equations based on the building's structural details, personnel count, internal load specifications, operational patterns, and local weather characteristics.

Comparing our actual case study results to ECView's estimations, we found an average error of 4.07 percent between actual and estimated values across all activities for the year, with minimum and maximum errors of 1.22 and 18.3 percent. We believe that these findings are close enough for ECView's practical use as a consumption estimator.

ESTIMATING DATACENTER CONSUMPTION

Because modern office buildings typically house datacenters, it is rapidly becoming essential for enterprises to monitor their datacenters' energy efficiency. As The Green Grid specifies (www.thegreengrid.org), the metric for datacenter efficiency is power usage effectiveness (PUE)—the ratio of total power entering a datacenter to the power required to support the IT infrastructure within the center. PUE is always greater than or equal to 1.0; the lower the value, the higher the efficiency.

A datacenter consumes power not only for the IT infrastructure but also to support equipment such as heating, ventilation, and air conditioning (HVAC) units; lighting; power distribution units; and uninterruptible power supplies (UPSs). Although a facility might be able to measure IT power directly from UPS panels, other devices might not lend themselves to such direct measuring. If the datacenter is inside an office building, for example (as in our case study), the chillers and air-handling units

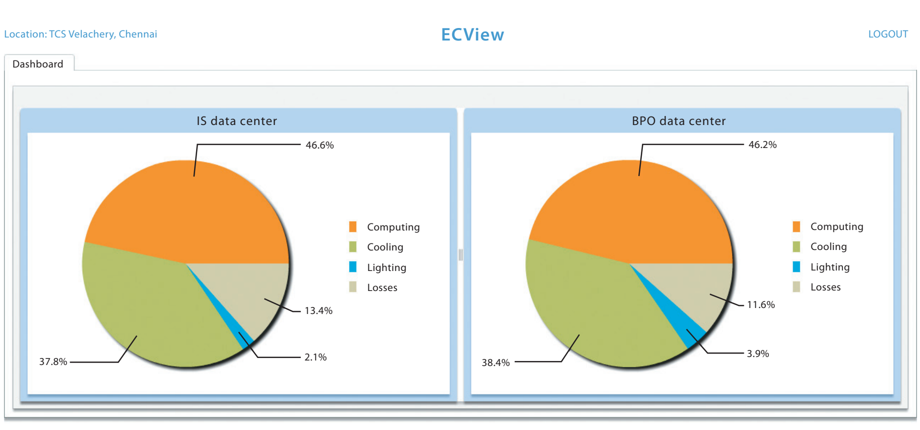

Figure 4. Breakdown of datacenter electricity consumption according to activity. ECView can apportion a datacenter's consumption even though a direct measure is for the building overall. In this view, the results reveal that the IS datacenter's power usage effectiveness is slightly better, in part because the IS datacenter has a lower proportion of lighting and cooling consumption.

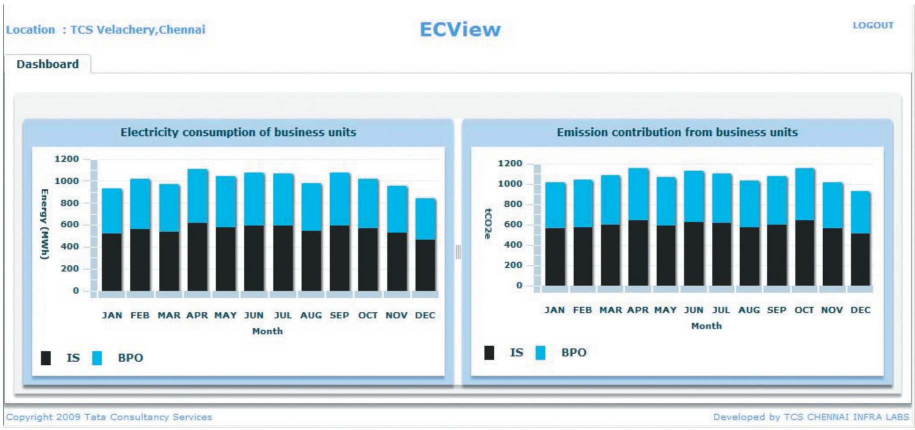

Figure 5. Electricity consumption and overall carbon footprint in terms of business units in the TCS building. ECView uses models to apportion consumption to business units or processes, since most buildings do not have metering at that level.

cool the entire building, of which the datacenter is only one part. Consequently, the unit meters will not show the consumption from the datacenter alone. In this scenario, ECView estimates the energy consumed in cooling the datacenter.

Figure 4 shows the electricity consumption for the two datacenters in the TCS building. ECView obtained operational data on the cooling assets from the building management system (BMS)—a centralized controller for air conditioning, access, fire alarms, and so on, which most nonresidential buildings have. Using this data along with the datacenters' structural details and equipment characteristics, ECView estimated the cooling energy consumed through mathematical models and arrived at the PUE for each of the two TCS datacenters: the PUEs of 2.14 for the IS datacenter and 2.16 for the BPO datacenter show that the IS datacenter is marginally more efficient.

PROCESS-LEVEL APPORTIONING

In addition to providing perspectives at the resource and activity levels, ECView can show energy consumption at the process level or by business unit. Generally, a building will contain several enterprise processes, and knowing which process or unit contributes what percentage to the building's carbon footprint can be extremely valuable in channeling emission abatement efforts. Each process becomes aware of its own footprint, which can lead to individually customized abatement strategies. Such insights can also serve as input to chargeback models for shared facilities.

Apportioning footprint and consumption at the process level is not a straightforward task, however, since most buildings have no metering at this level. ECView uses activity-level data as well as process-specific parameters to apportion the building's carbon footprint across processes. For example, the apportionment of energy consumed for lighting is based on design watts per square foot, area occupied by the business unit, and personnel count. The apportionment of desktop computing energy is based on personnel count, and the apportionment of energy required for cooling is based on heat-gain models. Figure 5 shows the individual energy and carbon footprints for the two processes in the TCS building.

From this data, we inferred that the building's annual electricity consumption per person is 4.25 MWh—for IS and BPO, per-person consumption is 4.78 MWh and 3.73 MWh, respectively. Despite having more people and desktops and a 24/7 operation, BPO's per capita footprint is lower than that of IS. After further investigation, we found that the IS datacenter was consuming about 93 kW; the BPO datacenter, roughly 23 kW. A study of IS's datacenter revealed that some servers were energy guzzlers even though they had a low utilization rate. This finding suggested a need for virtualization and consolidation. When considered along with the results of earlier datacenter PUE studies, we concluded that a low PUE does not automatically translate to efficient operation. Because the PUE does not completely reflect efficient power use, we recommend adding metrics that tie the use of IT asset utilization to datacenter power consumption.

The annual per capita carbon footprint for the building is 4.49 tonnes of carbon-dioxide equivalent (TCO2e), a standard metric for measuring greenhouse gas emissions; for the IS and BPO departments, it is 5.05 TCO2e and 3.94 TCO2e, respectively. IS's per capita footprint is roughly 20 percent higher than BPO's because IS personnel travel much more often and IS's overall electricity consumption is higher than BPO's. This observation prompted a suggestion to change the travel policy to reduce the TCO2e attributable to travel.

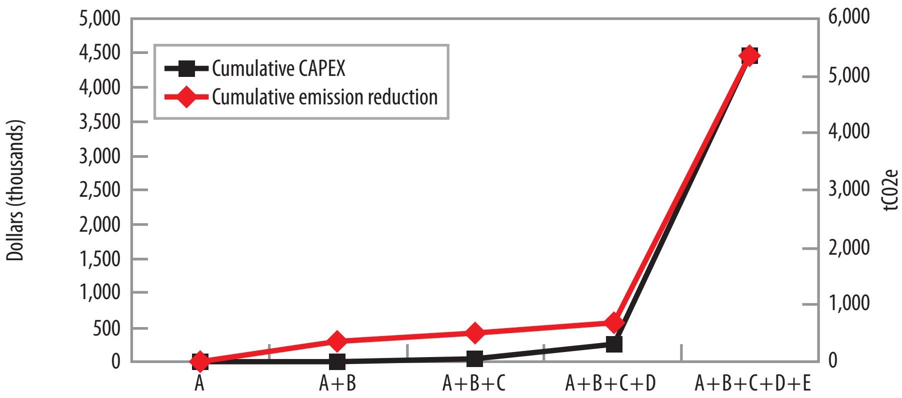

Figure 6. Carbon abatement measures using capital expenditure as the prioritizing index. Some of these measures, such as Option B, require no capital expenditure, yet they result in as much abatement as Option C, which requires a $25,000 capital expenditure. Option A represents the existing status (no abatement).

DECISION-MAKING SUPPORT

ECView has several features that aid decision making related to managing a building's carbon footprint, including the support for what-if carbon studies, an exhaustive database of carbon abatement measures, and the ability to chart optimal power purchases.

What-if carbon studies

ECView deepens the understanding of how business decisions and future actions affect a building's carbon footprint. Using the software's mathematical models to simulate hypothetical scenarios, decision makers can examine options related to the building's structural details and operational patterns. ECView does not restrict users to a menu of what-if options, which makes it possible to customize studies to clearly show the correlation between building operations and the carbon footprint.

For example, suppose the IS datacenter intends to expand its operations by adding 100 servers and that the servers' utilization percentage will not change. The manager might then want to explore how the additional servers would affect the building's annual electricity consumption and carbon footprint.

When we evaluated this what-if scenario with ECView, we found that improperly positioning the new servers would create hot spots that would greatly affect cooling and computing and cause the HVAC system to consume disproportionate energy amounts. ECView proposed a server placement strategy that would not create hot spots and showed that the building's annual energy consumption and carbon footprint would increase by 876 MWh (7.2 percent) and 641.5 TCO2e (5.01 percent), respectively.

Carbon abatement measures

From ECView's database of carbon abatement measures, users can customize an abatement strategy on the basis of the facility's assets, resource consumption, and operational pattern. Each measure has quantified values on the investment required, the carbon footprint reduction, and the payback period. Abatement curves prioritize measures according to a user-specified index.

Figure 6 shows curves that compare five abatement options in terms of capital expenditure. Option A is the as-is facility status with no abatement projects. Option B configures office desktops to hibernate during sustained inactive periods. Option C uses energy savers for lighting fixtures. Option D replaces the existing reciprocating chillers with absorption chillers. Finally, Option E purchases a dedicated windmill to provide the building with a green energy source. As the figure shows, a facility need not always spend a great deal for abatement. Some measures, such as Option B, are pure policy decisions.

Managing supply-side carbon

Most of the features we have described highlight managing the carbon footprint by optimizing the resource *demand*. ECView can also help managers more effectively manage the carbon footprint by optimizing the *supply*. Taking into account a building's location and energy demand profile, prevailing regulations, and available conventional and green energy sources, ECView can suggest the optimal green energy sourcing plan for that building.

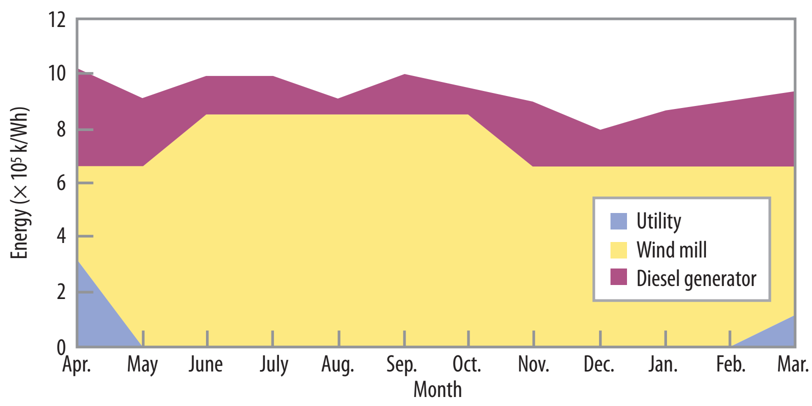

Figure 7. Optimal energy purchase plan for the TCS building in terms of cost. ECView ensures that any suggested plan satisfies availability and regulatory constraints. In this plan, a dedicated windmill provides most of the energy to the building.

Figure 7 shows the energy purchase plan suggested for the TCS building in our case study, which can reduce the facility's energy costs by 31 percent and its annual emissions by 59 percent.

Our case study of ECView shows that an IT framework can provide more insights into a building's carbon footprint than current intermittent energy audits. Even when a building does not have activity-level meters, ECView can estimate an activity's carbon use, proving that IT tools can fill the gaps and provide valuable insights. We have found, for example, that in a typical service-sector office building, HVAC is the largest individual carbon contributor followed by business travel.

ECView gives managers the freedom to explore carbon abatement measures and offers suggestions for optimizing power purchases. We have shown that in some cases carbon abatement strategies requiring zero investment could be as effective as those requiring a $25,000 investment. Armed with these insights and evidence that abatement options can be cost-effective, building managers have little reason to avoid green solutions for carbon management.

References

1. US Department of Energy, "Buildings Energy Data Book 2009"; http://buildingsdatabook.eere.energy.gov.
2. D.F. Carr, "A New Place for IT," 16 Nov. 2009; www.informationweek.com.
3. H.T. Johnson and R.S. Kaplan, *Relevance Lost: The Rise and Fall of Management Accounting*, Harvard Business Press, 1991.

Geetha Thiagarajan *is a scientist at TCS Innovation Laboratories in Chennai. Her research interests include renewable and sustainable energy system analysis. Thiagarajan received a PhD in electrical engineering from the Indian Institute of Technology, Madras. Contact her at geetha1.t@tcs.com.*

Venkatesh Sarangan *is a senior scientist at TCS Innovation Laboratories in Chennai. His research interests include computing and sustainability, radio-frequency ID systems, and wireless networking. Sarangan received a PhD in computer science and engineering from Pennsylvania State University. Contact him at venkatesh.sarangan@tcs.com.*

Ramasubramanian Suriyanarayanan *is a researcher at TCS Innovation Laboratories in Chennai. His research interests include developing IT-based solutions to help facilities, factories, and enterprises find economical green solutions to energy management. Suriyanarayanan received a BTech in computer science and engineering from SASTRA University, Tanjore. Contact him at ramasubramanian.suriyanarayanan@tcs.com.*

Pragathichitra Sethuraman *is a researcher at TCS Innovation Laboratories in Chennai. Her research interests include analyzing facilities' energy-consumption pattern, identifying the major carbon contributors, and determining appropriate methods to reduce the energy and carbon footprints. Sethuraman received a BTech in ceramic technology from Anna University. Contact her at pragathichitra.s@tcs.com.*

Anand Sivasubramaniam *is a professor of computer science and engineering at Pennsylvania State University and a consultant with Tata Consultancy Services. His research interests include computer architecture, operating systems and high-performance computing. Sivasubramaniam received a PhD in computer science from Georgia Tech. He is a senior member of IEEE and the ACM. Contact him at anand@cse.psu.edu.*

Avinash Yegyanarayanan *is an analyst at TCS. His research interests include datacenter power monitoring, building energy efficiency, and energy purchase planning applications. Previously, he was a researcher at TCS Innovation Laboratories in Chennai. Yegyanarayanan received a BTech in computer science from Vellore Institute of Technology. Contact him at avinash.y@tcs.com.*