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Green Transformation Workbench: A Practitioner's Tool for Carbon Management in Data Centers

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Green Transformation Workbench: A Practitioner's Tool for Carbon Management in Data Centers

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Abstract

There is increasing awareness that human activity may threaten delicate ecological systems. From evidence of global warming to concerns about water and soil toxicity, individuals and groups are asking what they can do to reduce their environmental impact. New technologies, processes and laws relating to carbon emissions and other environmental issues come forth and will seriously affect how companies operate in the future. Green transformation is increasingly a key management initiative in a corporate response to climate change. This paper presents a software tool, Green Transformation Workbench, which can help companies work toward the goals in logical, manageable stages as well as position them to reach the vision of a Sustainable Business and Corporate Social Responsibility. The Green Transformation Workbench is a framework that aligns processes, people and infrastructure of an enterprise to realize targets on carbon emissions. It implements a methodical approach that was devised to analyze green transformation opportunities and make business cases for transformation initiatives and thereby provides decision-support to the consultants. Unlike the traditional consulting methods and tools in the domain, the Workbench effectively addresses issues such as scalability of methodology, data and knowledge management, method enforcement, asset reuse and governance, consolidated views of upstream and downstream analyses well, to name a few. The Workbench is a practitioner's tool for business transformation addressing the issues. The Green Transformation Workbench builds on IBM's component business model [9, 17] and offers a consolidated view into data center operational components, processes, metric and infrastructure. It provides an intuitive way to evaluate and understand various opportunities in infrastructure consolidation and operational improvement. It embodies structured analytical models, both qualitative and quantitative, to enhance the consultants' practices. It provides diagnostics in data center operations based on benchmark data and business case analyses to the proposed green solutions. The Green Transformation Workbench has been instantiated with data from real-world data centers and applied to address a client situation as a case study.

1. Introduction

With increasing public awareness of environmental issues and concern about global warming, the growing inefficiency in a data center could be a public relations time bomb for the company. Even if the business is not overly concerned about its environmental profile, the financial aspects of inefficiency should be enough to spur action. Energy prices are rising rapidly, and IT power consumption is set to become a major cost center for many organizations. Beyond these direct costs, a sprawling, inefficient data center is also difficult and costly to manage and expand, and slow to adapt to new business requirements. This paper explores optimization strategies around the key areas of people, business processes and infrastructure in data centers, including entry points for analyses, relevant solutions, demonstrating benefits which were observed within the data center line of business of a world class IT service provider. Utilization of these capabilities will help data center practitioners meet the increasing challenges of energy efficiency, cost containment and compliance.

A *data center* is a facility used to house computer systems and associated components, such as telecommunications and storage systems. For most organizations, the growing importance of IT is putting pressure on space and resources in the machine room or data center. The historical tendency to add a new server and storage system for each new application means that many businesses have over-sized, inefficient IT infrastructures – often with additional departmental servers outside of the central facility. As demands for new applications and data storage grow, floor space, power consumption and heat output in the data center are becoming major issues. It is not just a question of rising costs for power and cooling – in many cases, organizations are coming up against the physical limitations of their data center facilities, in terms of how much floor space is available and how much power and cooling can be supplied. As more machines, running faster and hotter than the previous generation, are continually added, the carbon footprint of the typical data center is growing rapidly.

With the increased focus on energy awareness, many companies are now making an assessment of their data center efficiency. Collecting the data, analyzing it, and making improvements to the physical data center and its components are just a starting point. The data center is a living entity, constantly under change internally, but also under constant pressure for change due to variable outside influences such as political pressures, limits on available power, increasing environmental regulatory compliance requirements, and financial impacts such as ever-escalating power costs.

This paper presents a software tool, *Green Transformation Workbench*, which can help companies assess their data center efficiency and identify enhancement opportunities in logical, manageable stages. The Green Transformation Workbench is a framework that aligns processes, people and infrastructure of an enterprise to realize targets on carbon emissions. It implements a methodical approach that was devised to analyze green transformation opportunities and make business cases for transformation initiatives and thereby provides decision-support to the consultants.

The Green Transformation Workbench builds on IBM's component business model [9, 17] and offers a consolidated view into data center operational components, processes, metric and infrastructure. It provides an intuitive way to evaluate and understand various opportunities in infrastructure consolidation and operational improvement. It embodies structured analytical models, both qualitative and quantitative, to enhance the consultants' practices. It provides diagnostics in data center operations based on benchmark data and business case analyses to the proposed green solutions. Unlike the traditional consulting methods and tools in the domain, the Workbench provides additional tools for effectively addressing issues such as scalability of methodology, data and knowledge management, method enforcement, asset reuse and governance, consolidated views of upstream and downstream analyses well, to name a few. The Workbench is a practitioner's tool for business transformation addressing the issues. The Green Transformation Workbench has been instantiated with data from data centers from a world-class IT service provider and applied to address a client situation as a case study.

The rest of this paper is structured as follows: In Section 2, we provide a motivating example of green transformation and explain we want to approach the problem in comparison with previous work. Section 3 provides an overview of our approach, a practitioner's tool for green transformation and explains its models and methodology. It provides a consolidated views linking various models in enterprises, both qualitative and quantitative financial analytics of business transformation initiatives, and reporting. Before providing the details of the functionality and analysis capabilities of the tool, Green Transformation Workbench, in Section 4, we will explain what data is required and collected for the analyses. Section 5 describes in more detail the CBM-based qualitative business analyses, i.e., Green Transformation Diagnosis system. Section 6 focuses on the quantitative financial analytics of business transformation initiatives, i.e., Green Business Case Analysis system. Section 7 discusses the future extensions of the presented work. Finally, in Section 8, conclusions are drawn and future work is outlined.

2. Related Work

With today's market realities – rising energy costs; shrinking power and space capacity; increased regulatory scrutiny; and higher customer expectations, going green is not only a socially responsibility but also an economic imperative. Traditional green IT strategies have focused on the data center alone, which accounts for 2% of global CO_2 emissions [4, 6, 15, 21, 22, 26]. IT can significantly reduce the other 98% requiring a new paradigm – one which IT is the key to realizing energy efficiencies throughout the organization – dramatically reducing environmental impact and energy costs.

There is a "perfect storm" gathering around energy consumption worldwide, as organizations and businesses face the unprecedented convergence of increasing energy demands and costs, diminishing capacities, heightened awareness and rigorous regulatory scrutiny. Governments are placing tighter restrictions and regulations around energy generation and consumption. For example, the European Union (EU) announced that 20% of its total energy usage will come from renewable sources [3, 4, 15] – a goal far beyond Kyoto requirements [5, 28, 29, 30]. Organizations have to improve their energy efficiency to comply with external and internal goals and regulations, and be able to track their energy consumption and report on their improvements. Several regulations are already in place and more are coming. Energy costs are increasing worldwide. Energy availability is no longer a given. Customers worldwide are being capped on their available power. The impact spans all aspects of energy consumption but is especially critical with the rapid growth of data center needs. In a recent survey, approximately 70% of data center owners cited the availability of power and cooling as their number one concern [6, 22, 23, 24, 31].

We are simultaneously experiencing a change in how we do business. Online collaboration has reduced the need for travel, but the resulting rapid increase in worldwide collaborative operations and access to systems is pressuring IT systems to 24x7 availability and further increasing the energy demands of IT. It is estimated that IT workloads double every two years, driving the need for additional servers, storage, and supporting infrastructure, not to mention the staffing required to maintain these systems. The increased staffing enlarges the carbon footprint and further drives energy demand from facilities like office space, lighting, power and cooling.

There is also a growing social responsibility aspect that is particularly prominent in some parts of the world such as the EU. Organizations are realizing that being green is good for business, positively affecting brand image and fast becoming a competitive differentiator for customers, partners and suppliers. The fact that going green can reduce costs and thus improve the bottom line simply increases the level of interest ingoing green.

For all the reasons, there is now significant pressure on businesses to reduce the physical footprint of servers in the data center, cut heat output and power consumption, and reduce the speed at which the infrastructure needs to grow. By taking positive steps to tackle the carbon management issue in the data center, the business can also benefit by reducing operational costs and gaining flexibility. Customers are instituting a range of solutions to improve their energy efficiencies. From industry leading data compression to tiered data storage techniques; to increased use of virtualization; to tighter integration of IT and facilities; to monitoring and reporting on IT component energy usage, customers worldwide are placing a focus on understanding their energy utilization and addressing its impact from both a financial and environmental perspective.

Server consolidation is a relatively straightforward initial tactic in the strategic move towards an efficient, environmentally sound, low-cost infrastructure. By consolidating a large number of decentralized and under-utilized servers to a smaller number of more powerful machines in a central location, the business may be able to cut capital and operational expenditure both now and in the future. As well as cutting the cost of hardware acquisition by squeezing more out of existing hardware, a well-managed program of server consolidation can significantly improve quality of service, flexibility and speed of response to new business requirements. Moreover, reducing the total number of servers and storage systems will generally cut power consumption and heat output, shrinking the organization's carbon footprint. A smaller, more efficient IT infrastructure should reduce hardware maintenance costs, and may also enable significant savings on software licensing.

Currently there is a focus on deploying more efficient systems and on tracking energy consumption. Projects with the primary focus on increasing greenness are also exploring optimization of business process along with infrastructure improvements. As the energy stakes rise, a more pervasive approach which aligns processes, people and infrastructure of an enterprise and analyze green transformation opportunities to realize targets on carbon emissions is essential. The Green Transformation Workbench takes the pervasive approach to helping organizations go green from the inside out.

3. Overview: Green Transformation Workbench

Green Transformation Workbench (GTW) provides an integrated view of various business models and data, including a component business model, a business process model (e.g., APQC (American Product Quality Council) Process Classification Framework [1] and SAP Business Process Hierarchy), a value driver model, an infrastructure map, an organization structure map, and a solution catalog, with the models linked each other, as shown in Figure 1. The workbench helps organizations understand and transform in three key areas, i.e., business processes, infrastructure, and organizations.

The business processes are executed by people on the infrastructure within organizations, and their underlying tasks and applications directly influence energy needs. Effective operational management includes the ongoing improvement of business and IT information and processes to ensure that a continual focus is placed on reducing the carbon impact of the organization. GTW helps understand the efficiency of business operations with processes and infrastructure designed to maximize energy efficiency while meeting business needs. The infrastructure of a company, such as data center systems, buildings, factories, trucks, etc., is a major consumer of energy. In fact, the industrial sector consumes 47% of worldwide energy demand. GTW helps organizations visualize, how the infrastructure to deliver power efficiency and optimize operations by leveraging consolidation and virtualization. The organizations directly and indirectly contribute to the carbon footprint in a range of ways, from the impact of cycle-time involved in various projects, to the physical office space and its energy requirements. The workbench helps organizations optimize the use of people resources and collaboration beyond boundaries to drive business growth while reducing travel and physical real estate costs.

For such analyses, GTW automates the traditional component business model-based analyses by using visual queries and inference. The qualitative business analyses using the visual queries and inferences in the tool are generally referred to as *daisy chain analysis*. An example of the daisy chain analysis in the workbench is the 'heat map' analysis where it automatically discovers underperforming business components in the map and color them based their performance, as shown in Figure 1. It first identifies the metrics associated with each component, compare their as-is values against the industry benchmark values. Underperforming components are ones associated with metrics whose as-is value is worse than the benchmark value. Another example of the daisy chain analysis is the 'shortfall assessment' of infrastructure and organization. The workbench infers and associates infrastructure systems and organizations with each business component, and renders them in the business component map. Then the user can visually identify and categorize shortfalls (or transformation opportunities) in infrastructure and organizations such as 'gap,' 'deficiency,' 'duplication,' and 'over-extension.' Once the transformation opportunities are identified, then the tool also discovers solutions that may address the shortfalls by using the similar daisy chain analysis.

Once one or more transformation solutions for IT and/or organization are discovered, GTW also provides a quantitative analysis on them, i.e., the *business case analysis* in terms of standard financial metrics such as NPV (Net Present value), IRR (Internal Return Rate), ROI (Return on Investment), and Payback time. Additionally, the workbench provides carbon benefit analyses for each solution category by using green metrics such as Internal

Cost of Carbon per ton and percentage reduction in carbon. The workbench provides normative and constructive business performance analysis models, and so it can be easily configured for different types of clients, initiatives, and projects.

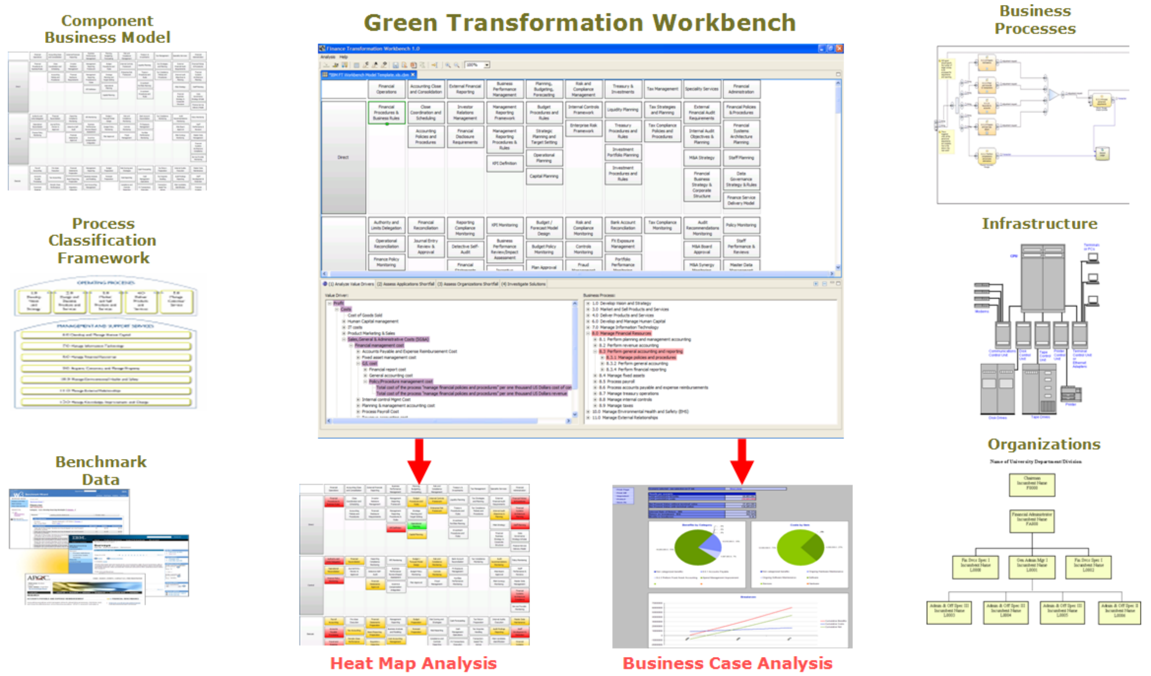

Figure 1: Overview of the Green Transformation Workbench

GTW employs a phased methodology that relies on assessment, analysis and prioritizing transformation solutions, as displayed in Figure 2. The initial diagnosis phase identifies the business pain points in the components by comparing the as-is values on value drivers with the industry benchmark values from best practices. The result can then be used to help identify transformation opportunities in infrastructure and organizations with scope for improvement. The daisy-chain analysis help discovering the solutions to mitigate the pain points which can be further analyzed for carbon-cost benefits by using the business case modeler. By conducting benefit analyses iteratively with various combinations of solutions, the user can prioritize them for their significance and create a road map for final action. Among the steps shown in Figure 2, this paper focuses on the following three steps, while other will be discussed in other space:

- *Green Diagnosis System* for identifying "hotspots" of carbon reduction in the as-is enterprise IT management practice and for assessing the as-is practice to identify and categorize 'shortfall' areas for carbon reduction,
- *Green Solution Discovery System* for automatically identifying (and composing) solutions (by using the daisy-chain analysis) for addressing the identified 'hotspots' and 'shortfalls,' and
- *Green Business Case Analysis System* for assessing cost vs. (carbon) benefit, resolving and optimizing investment and benefits, and prioritizing initiatives based on the combined sets of options.

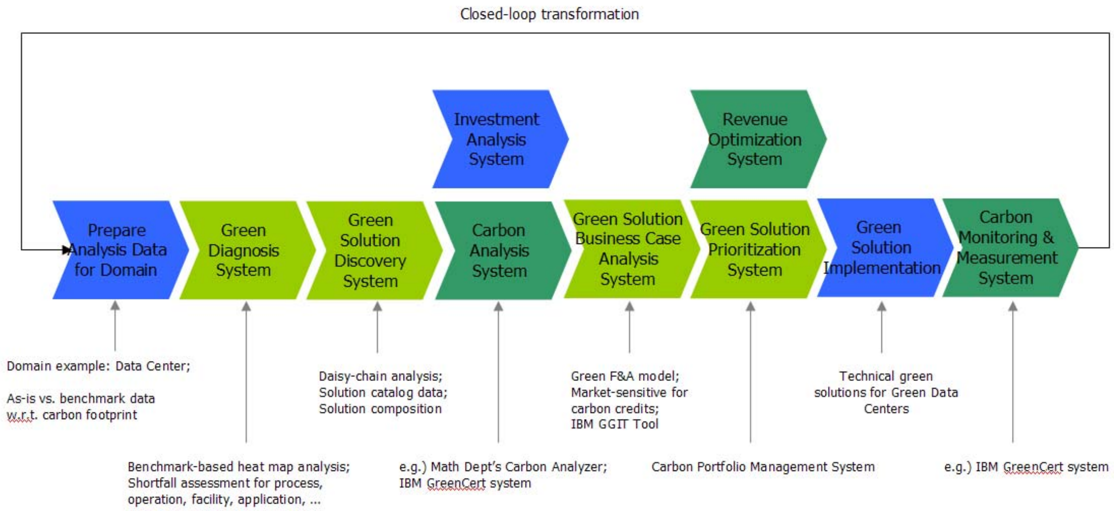

Figure 2: Overview of the green transformation methodology

The Green Diagnosis System utilizes IBM's Component Business Model-based business transformation methodology [9, 16, 17] that represents enterprises in a consolidated view, grouping together similar business activities as a business component and classifying business functionality into non-overlapping components. It identifies business processes and activities associated with each business component. It utilizes the daisy-chain analysis for the heat map analysis and shortfall assessment to identify transformation opportunities in the current environment – infrastructure and organizations.

The Green Solution Discovery System also utilizes the daisy-chain analysis and one or more solution catalogs to identify green transformation initiatives to address the discovered shortfalls and support the intended business transformation. Green performance metrics (value drivers) allow the analysis tool to discover and recommend solutions to fill "green" shortfalls in processes, organizations, and infrastructure.

The Green Business Case Analysis System utilizes IBM's Green Business Case Calculator (GBCC) [17] which is an MS Excel-based tool, with a pre-built template for conducting financial and carbon analysis of the chosen solutions. For each category of solutions, GBCC identifies cost and carbon benefits, allows distribution over year producing a cost-carbon flow up to 25 years from now and consolidates the overall analysis with financial and carbon metrics. The financial model calculates the standard metrics such as Return on Investment (ROI), Net Present Value (NPV) and Internal Rate of Return (IRR) of the project, and break even period. The carbon model provides ROI (Reduction on Investment) and ICC (Internal Cost of Carbon) of different categories of green solutions. An executive summary represents financial and green results graphically. Figure 3 illustrates the features of IBM Business Case Calculator.

Among the steps in the green transformation methodology shown in Figure 2, ones out of these three components, i.e., the Green Diagnosis System, the Green Solution Discovery System, and the Green Business Case Analysis System may be implemented by utilizing existing industry solutions [8, 10, 11, 12, 13, 14]. We will not address them in this paper, because they are out of the scope of this work.

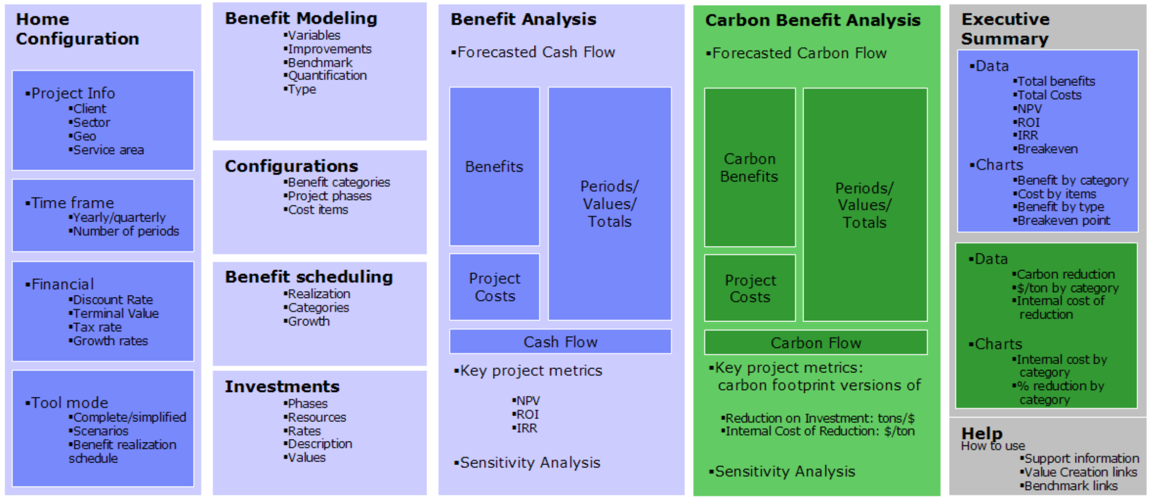

Figure 3: Overview of the Green Business Case Calculator

This paper describes how GTW is used for transforming data centers as a case study. It explains the operations of data centers, and goes through the steps the GTW users takes in the green transformation analyses: the data preparation, the diagnosis steps, the solution discovery step, and the green business case analysis. It describes how the green transformation methodology introduced in the previous section is applied to systematically identify opportunities for green improvement and to evaluate the potential transformation projects.

4. Data for Analysis

Before conducting the green transformation analyses using the GT Workbench, certain data should be prepared. The data preparation takes two steps: the first step is to prepare various models of data center's operational functions. The models include a component business model of its business, the process model, the organizational model, a set of infrastructure equipments that help implement the operations under investigation, and a set of metrics that help measure the performance of the processes and the activities. In the second step, all of these models are linked with one another by the consultants for helping inference with the daisy-chain analysis.

4.1. Component Business Model

Component Business Model (CBM) is a method developed by IBM to help analyze clients' business from multiple perspectives such as people, process and technology [9, 17]. The intersection of these views offers is claimed to improve insights for decision-making. A CBM is, in essence, a component view of a business where all the similar business activities of a given company's business processes are grouped into business components. A sample component business map is represented as a two dimensional matrix: The columns are created after analyzing a business's functions, competencies, and value chain. The rows are defined by actions and their accountability levels. The top row, "direct," represents all those components in the business that set the overall strategy and direction for the organization. The middle row, "control," represents all the components that translate those plans into actions, in addition to managing the day-to-day operation of those activities. The bottom row, "execute," contains the business components that actually execute the detailed activities and plans of an organization. The *Component Business Map* shows activities across lines of business, without the constrictions of geographies, internal silos or business units. The component business map for a company is typically represented on a single page. A *business component* is an abstract business element. It is a collection of similar and related business activities from various business processes [9, 17]. From this point of view, business processes can be thought of as flows of activities between and within components. A component is defined by a set of people, processes and technology needed by its business function.

By working with practitioners of data centers, we created a component business map of data centers, with each component relating to business functions or operational phases at each level of accountability. In a service engagement, the business consultant, i.e., the user of GTW, will collaborate with various teams in the data center operational practice and identify non-overlapping business units to ensure the collectiveness completes all the functions. Then business shortfalls can then be identified from the consolidated view, providing a high level overview of the data center practice. Figure 5 shows the Component Business Model map for data center operations with seven business competencies at three level of accountability, altogether handling data center functions in its entirety.

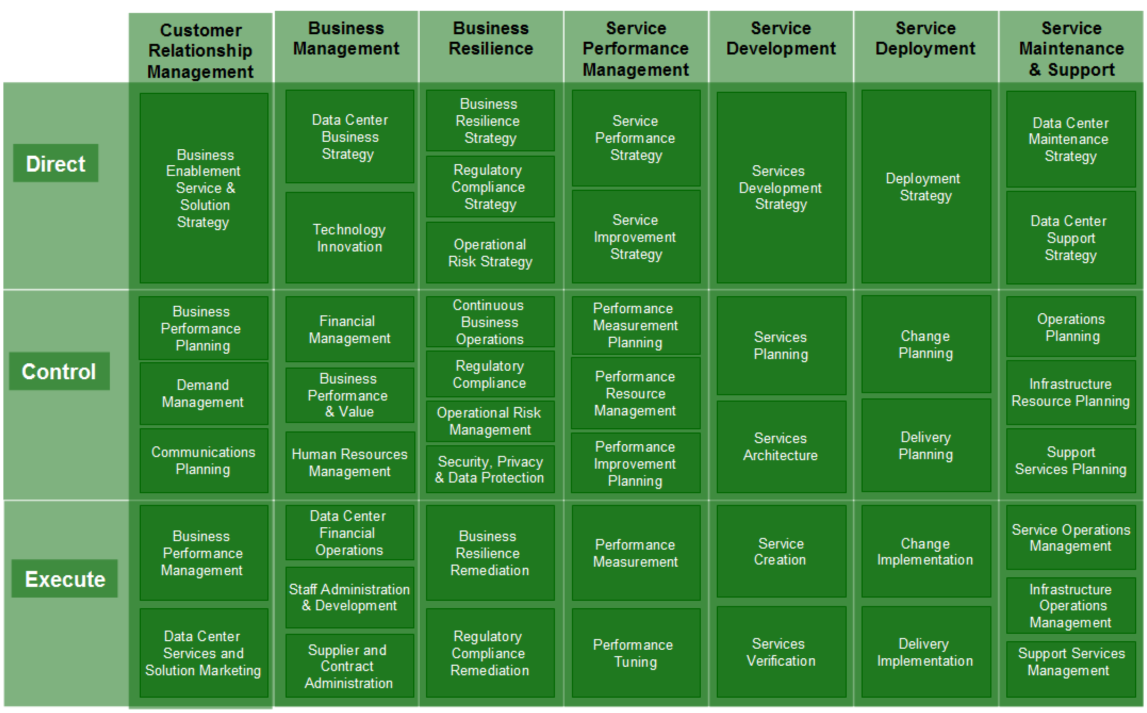

Figure 4: Component business map for data centers

The competency of the Customer Relationship Management shown in Figure 4 serves external communications in developing and maintaining data center offering. Business Management develops strategies and manages finance, technology, staff and vendors to conduct business effectively. Business Resilience involves handling unexpected situations and managing risk assuring business continuity. Service Performance aims to monitor and optimize data center services making the performance parameters transparent across the verticals to enable collaboration for required actions. Other three competencies handle lifecycle operations of data centers in developing, deploying and maintaining the services. One may observe the aggregation of these components exhaust the all of the data center functions.

4.2. Business Processes

A *business process* is a flow of one or more business activities [9, 17]. A business process when executed accomplishes a specific business objective. A *business activity* is the lowest level task in a business process [9, 17]. A business process in a data center is an operational task to manage the business, maintain the facility and enable service. At a high level, it involves managing facility, people and technology with various aspects of operational activities assigned. As the details increase, the process may describe the technical task as one of the step in accomplishing respective function. The process hierarchy in data centers begins with three root processes: manage data center, develop and manage human capital, and manage technology. Figure 5 shows the operational processes of data centers in detail.

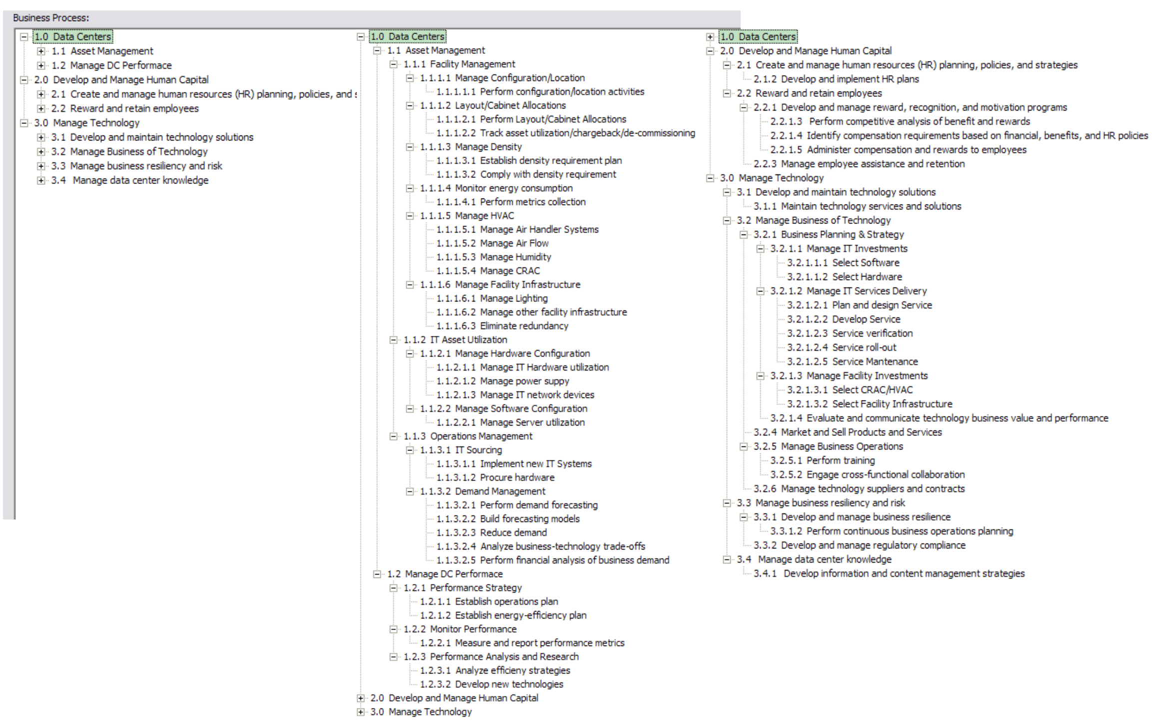

Figure 5: Business processes of data centers

The initial branch of data center management involves maintaining assets and improving their performance. Assets include IT, power distribution, UPS (uninterruptible power supply), network equipment, HVAC (Heating, Ventilating, and Air Conditioning) and other infrastructure. The scope for optimizing asset usage dwells into every category with multitude of solutions with varying benefits. On the other hand, there are various processes in managing human capital and technology for efficiency. Each business component constitutes a collection of business processes which communicate to other components to achieve operational completeness.

4.3. Performance Metrics

Identification of business value for a data center can be tracked from varying levels of detail in technical and operational setting. The associations between value drivers and business components are discovered through their relationships with business processes and activities defined by a business consultant. An ideal strategy is to track a set of value drivers to respective benchmark values and identify the road map strategies. Since a data center is in fact an emerging area of research with plethora of opportunities for efficiency, GTW provides flexibility in the model to compute business benefits based on the consultant's domain knowledge. This model allows three types of value drivers and performance metrics identified for data center operations:

Efficiency and Quality Metrics

A generic value driver captures the performance as the percentage of efficiency which can be improved by a variety of solutions which may be analyzed during a client engagement or test deployment. These ones are the standard metrics available and practiced in the industry representing the efficiency levels of facilities such as cooling, power systems, lighting, network, IT system including CPU utilization, and productive proportion of deployed systems.

Technical Measures

These metrics include physical ones that denote operational status of a data center such as Cooling Power Density and Average UPS load. When the measures are tightly coupled with economic factors, it provides an accurate assessment of business value and so decision making support. GTW allows advanced users to make use of these metrics in the related solutions in identifying target benefits. In this regard, GTW relies on consultant's knowledge and accuracy to provide realistic information, as the rest of the analysis is sensitive to the benefit levels identified at this stage.

Reduction Factors

GTW bases its core computation of the business value matching the present and target values of DCiE (Data Center infrastructure Efficiency) with solutions chosen. Each solution's impact on DCiE is measured by percentage improvement, hopefully in a positive way. The impact factors termed *reduction factors* in GTW allows to build a business case with minimal details and improve the case incrementally with additional developments. The reduction factor denotes the impact of the performance metric in context of study, for example, DCiE impact by improving CRAC (Computer Room Air Conditioner). Here are more details of DCiE and related factors:

$$DCiE = IT\ equipment\ power\ /\ Total\ facility\ power$$

Typical DCiE in industry is known to be 0.33 [18, 19, 21, 22, 26, 27]. The reverse value of DCiE is known as Power Usage Effectiveness (PUE), and also used as a popular metric:

$$PUE = 1 / DCiE$$

The best practice value of PUE in 2008 is known to be 1.8 [18, 19, 21, 22, 26, 27].

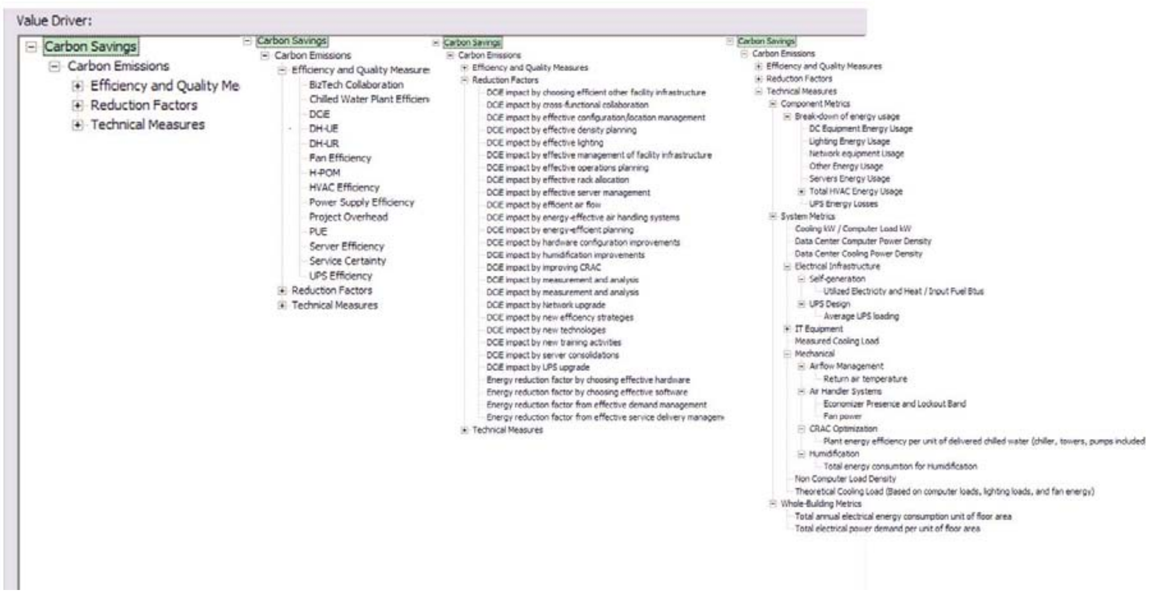

Figure 6: Value drivers for data centers

Additionally, there are a few other related metrics suggested and used by industry practitioners. IT Hardware Power Overhead Multiplier (H-POM) measures how much of the power input to a piece of hardware is wasted in power supply conversion losses or diverted to internal fans, rather than making it to the useful computing components, and is defined as follows [21, 22, 26]:

$$H\text{-}POM = \textit{AC hardware load at plug} / \textit{AC hardware compute load}$$

Deployed Hardware Utilization Ratio (DH-UR) measures the fraction of IT equipment which is not productive, and is defined as follows [21, 22, 26]:

$$DH\text{-}UR = \#\ \textit{servers running live applications} / \textit{total}\ \#\ \textit{of servers deployed}$$

Finally, Deployed Hardware Utilization Efficiency (DH-UE) measures the opportunity for servers to increase utilization by the virtualization and is defined as follows [21, 22, 26]:

$$DH\text{-}UE = \textit{min.}\ \#\ \textit{servers to handle peak load} / \textit{total}\ \#\ \textit{of servers deployed}$$

Due to the abstract nature of data center efficiency initiatives, this study focuses on improving the performance metric, i.e., DCiE (Data Center infrastructure Efficiency) introduced above, by identifying the percentage change in DCiE realized by each solution applied. It is then used to compute detailed benefits by further business case analysis using the BCC tool also introduced above. Figure 6 shows the value drivers and their structure for data centers in detail.

4.4. Organizations

Along with the infrastructure, the organization of a data center (and any other enterprise) supports the operations of the business processes and so provides an area for business transformation including green transformation. We interviewed a number of data center practitioners to understand the typical organizational structure of data centers supporting the business processes presented in Section 4.1.2. Figure 7 shows the organizational structure in a typical data center in three areas: business, operation and technology.

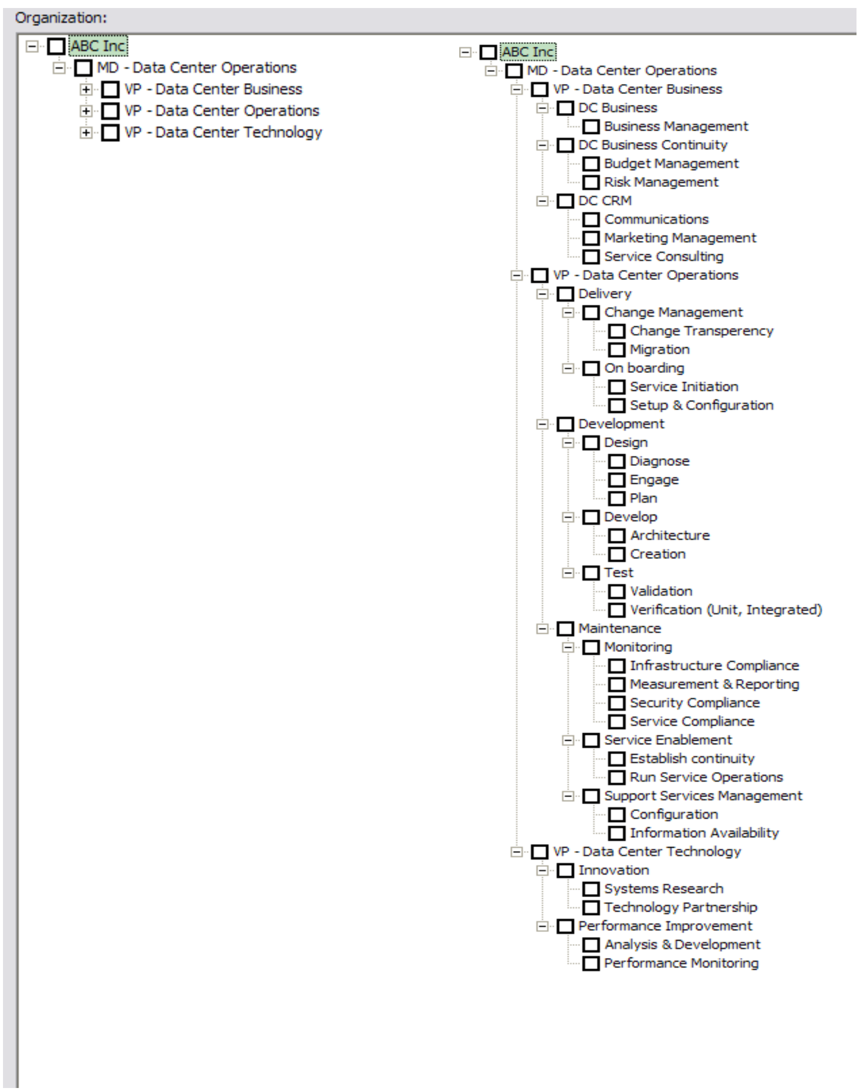

Figure 7: Organization structure of data centers

4.5. Infrastructure

Along with the organization, the infrastructure of a data center (and any other enterprise) supports the operations of the business processes and so provides an area for business transformation including green transformation. We interviewed a number of data center practitioners to understand the typical infrastructure of data centers supporting the business processes presented in Section 4.1.2. Figure 8 shows the infrastructure structure in a typical data center in service areas: Analysis, Infrastructure Equipment (Compute Service), Integration, Measurement, and Server Efficiency.

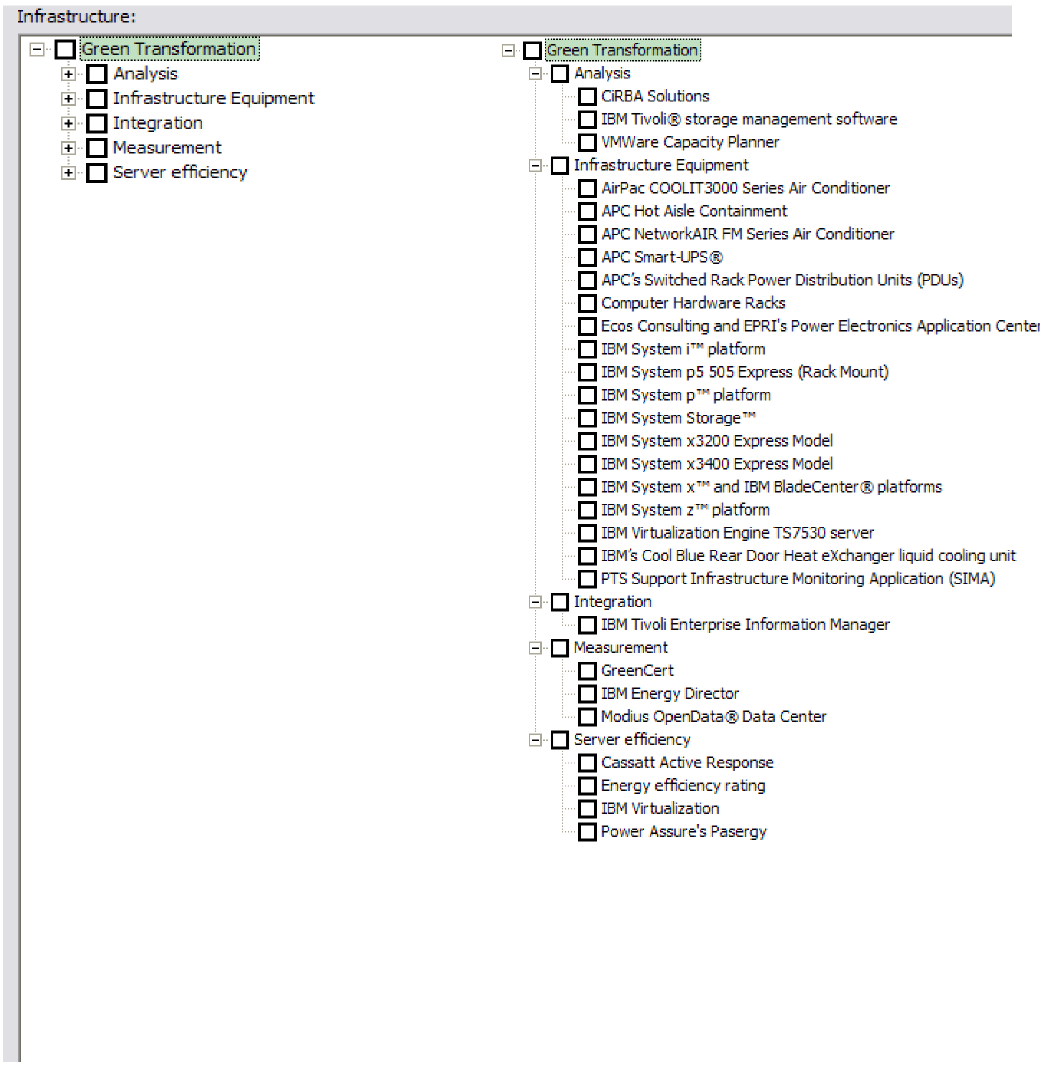

Figure 8: Infrastructure of data centers

4.6. Solutions

This part provides a catalog of solution that may be applied to address shortfalls in the current organizations and infrastructure of data centers identified by using the CBM-based qualitative business analysis. Examples of such shortfalls include poor demand and capacity planning within and across functions (business, IT, facilities), significant failures in asset management (e.g., 6% average server utilization, 56% facility utilization), and the board not being able to hold CIO accountable for critical data center facilities and other operational efficiency.

The solution can be a combination of one or more of hardware, software, and services. Also, GTW does not limit the proposed solution to only turn-key solutions and shrink-wrapped solutions. Also, by augmenting GTW with solution composers which helps to design and implement downstream technical solutions by using such services as Web services on SOA meeting the given requirements for green transformation. Also, solutions suggested by GTW can be consulting services in the process transformation or business strategy area. Figure 9 shows a sample solution catalog for data centers.

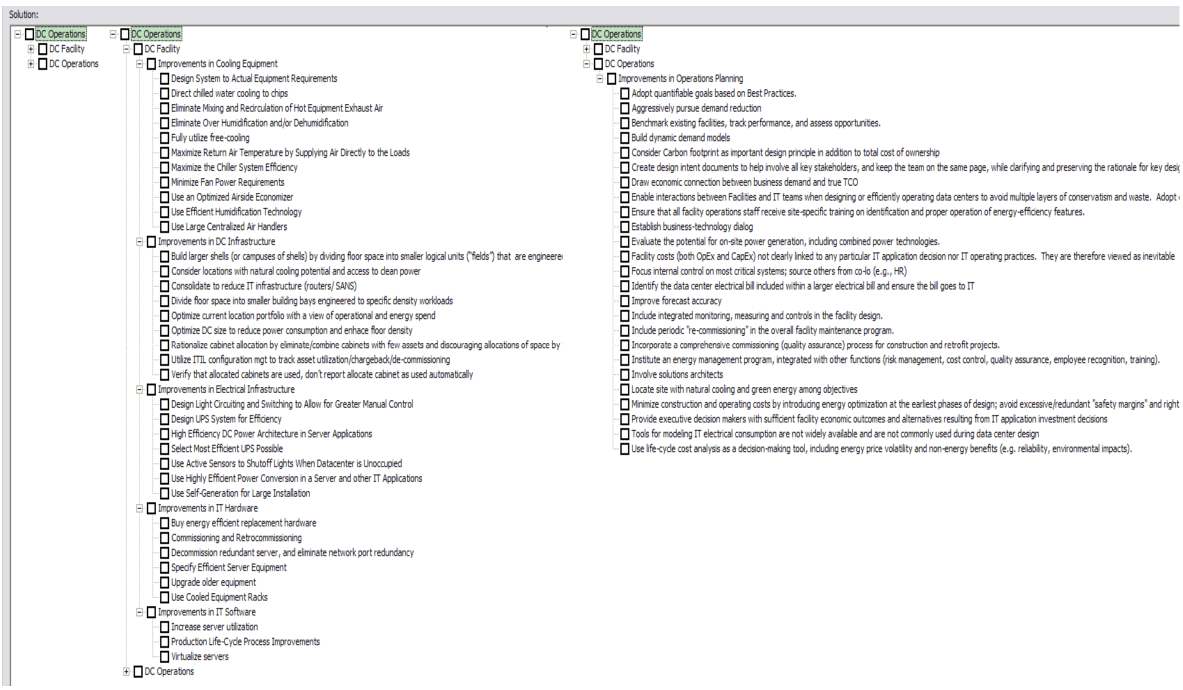

Figure 9: Green solution catalog for data centers

4.7. Model Association

In GT Workbench, models described until now are mapped to each other. We refer this linking of models and the ability to query them to "daisy-chain analysis." With the daisy-chain of models, the user can see all the business processes and activities that are associated with a business component. In turn, the user can see all the metrics (along with their values) and value drivers of the selected business processes, and so s/he can qualitatively see the overall performance of the component. For the 6 base models described until now, the user can provide a set of initial model association to business processes as part of the data preparation for GTW analyses – 5 types of links, i.e., Comp2BizProc, VD2BizProc, Infra2BizProc, Org2BizProc, and Sol2BizProc. That is, we use a hub-and-spoke approach to linking the models, i.e., all models are linked to the business process model instead of each model linking to each other model as shown in Figure 10.

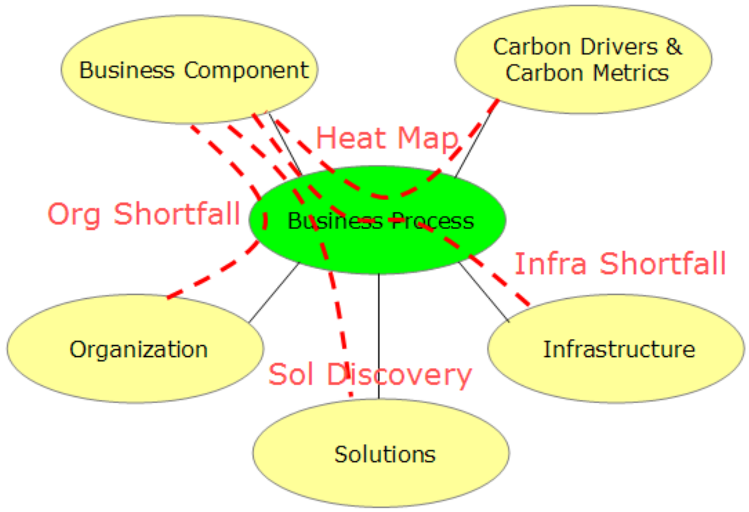

Figure 10: Daisy-chain of models

Daisy-Chain analysis allows navigation across the integrated view of models to see the direct *and* indirect relationships among models. The tool infers the indirect ones from the direct ones by using the transitive relationships. The heat map analysis, as shown in Figure 11, is an example of a daisy-chain analysis. The heat map is generated by comparing the values of the carbon drivers and metrics (indirectly) associated (through business processes) with business components. The green shortfall analyses such as the organization and infrastructure shortfall assessment are also applications of the daisy-chain analyses. They utilize the indirect relationship of the infrastructure and organization entities to business components, which are, in the tool, visualized as graphical overlays so that the user can visually identify and categorize shortfalls. Another example of the daisy-chain analysis is the solution discovery which discovers one or more solutions for business components with shortfalls by using the inferred relationships. Figure 11 shows a daisy-chain of models with sample entities for each model.

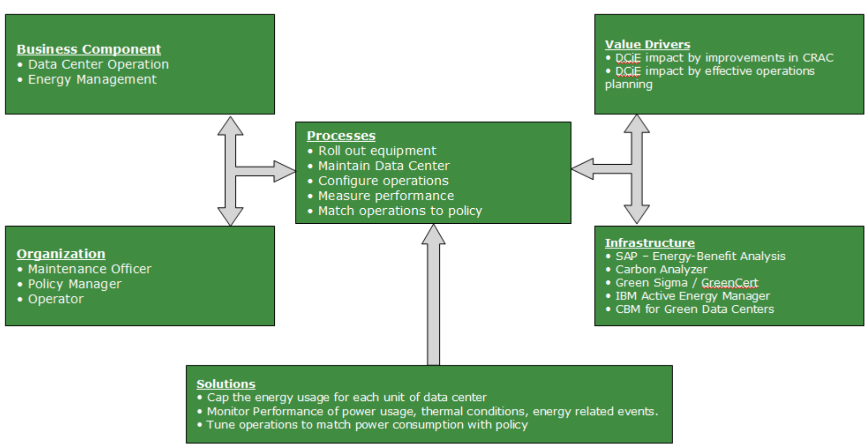

Figure 11: Daisy-chain of models with sample model entities

All of the above data described in this section, both base model data and the association data, is collected in a single place, particularly in GTW, in an Excel file with a specific but flexible format referred to as *Model Template* in GTW, as shown in Figure 12. Once all the necessary data is prepared in the Model Template, the GTW user is ready to conduct the green transformation analyses on the data center's operational functions.

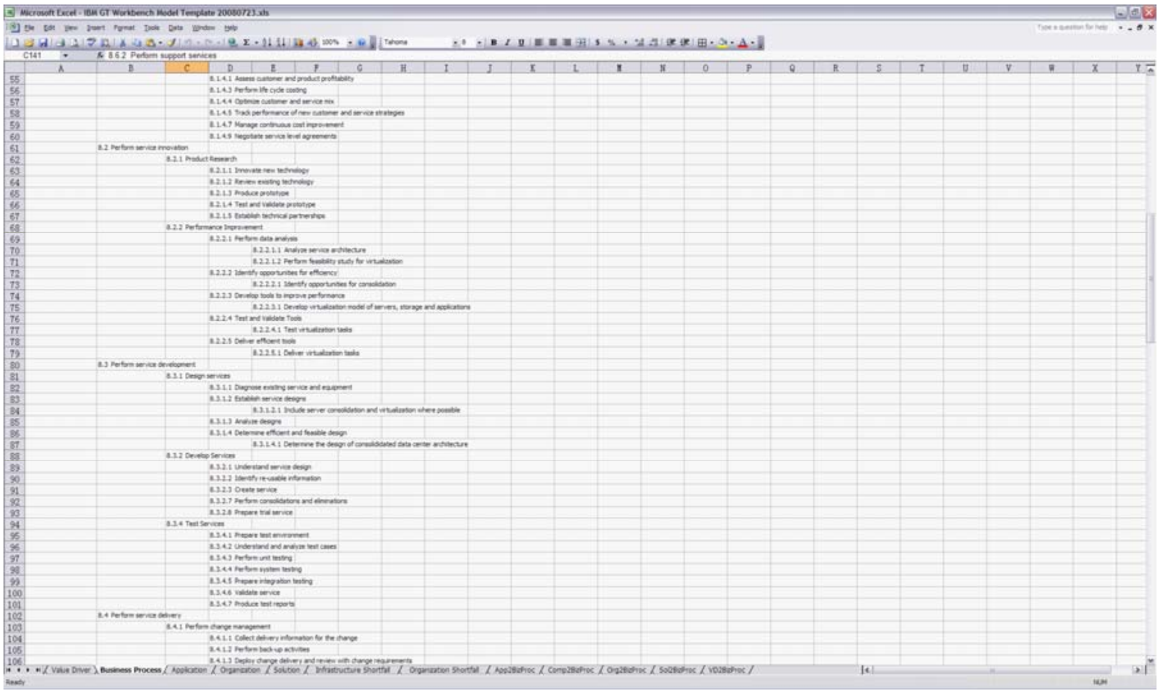

Figure 12: Data prepared in an Excel file for GTW analyses

5. Green Transformation Diagnosis

The Green Transformation Diagnosis System in GTW utilizes the Component Business Model-based business transformation methodology that represents enterprises in a consolidated view, grouping together similar business activities as a business component and classifying business functionality into non-overlapping components. It utilizes the daisy-chain analysis for the heat map analysis and shortfall assessment to identify transformation opportunities in the current environment, i.e., infrastructure and organizations.

5.1. Heat Map Analysis

The Heat Map Analysis is an essential capability of CBM where the user discovers one or more "hot" components that are associated with one or more business strategies and/or pain points. In the traditional CBM analysis, this step was conducted manually by the business consultants relying on his/her knowledge and expertise in the business domain. The GT Workbench automates the capability as visual queries, by taking metrics values into account with the analysis. First, the system allows the user to explore the value driver tree to identify one or more value drivers that may be associated with a certain business strategy/pain point. The discovery of "hot" components that affect the business strategy can be accomplished. Then the system colors the identified hot components differently to distinguish ones that affect positively or negatively to the strategy. The GT Workbench system compares the industry benchmark and the as-is value of the operational metrics and performance indicators associated with the components to decide on their color.

In this study, the reduction metrics associated with the data center operational processes are compared with the industry benchmark levels obtained by surveying. The business components whose metrics underperform in comparison to the industry benchmark values are highlighted in yellow. The components whose metrics underperform in comparison to the industry average values are colored in red. The components whose metrics perform above the industry benchmark values are highlighted in green. A sample heat map that is generated for ABC Inc. is shown in Figure 13. This green performance analysis indicates that the metrics associated with performance tuning function of ABC Inc. underperform by 30% in comparison with the industry's best practice and by 15% in comparison with industry's median.

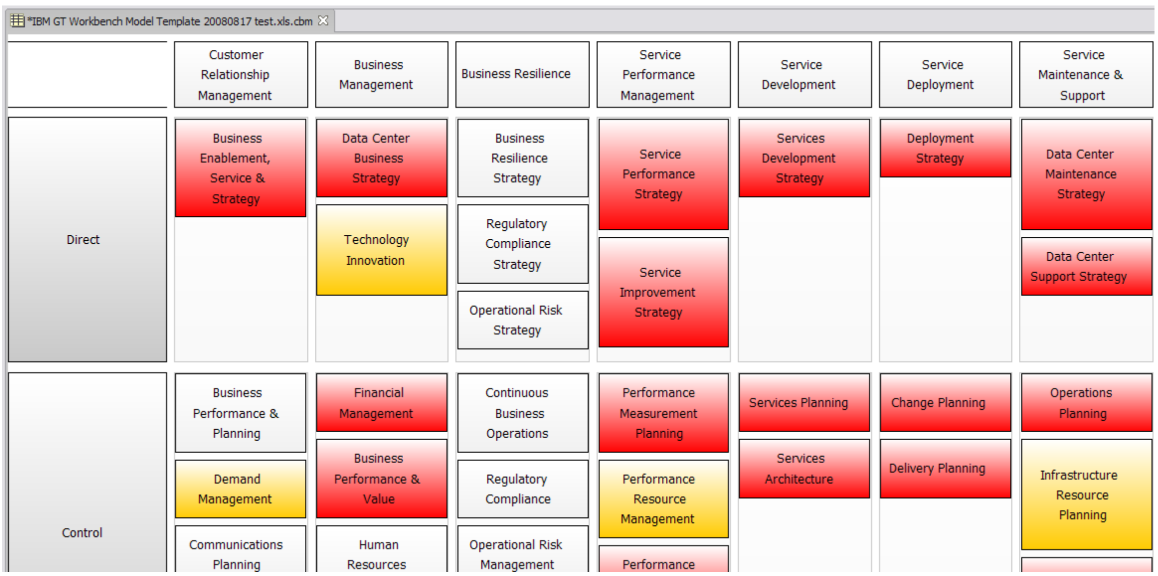

Figure 13: Heat map in GTW

5.2. Shortfall Assessment

The Shortfall Assessment allows the user to map the existing infrastructure or organization structure of a data center against the "hot" components identified in the Heat Map Analysis. It helps understand how the current infrastructure or organization structure, such as applications, network capabilities or certain departments, supports the business, especially, for those hot components. The analysis requires collecting the information on the current infrastructure or organization structure. Then the mapping of IT applications or organization structure to the components becomes, again, an execution of a simple data query to the basic model mapping.

GT Workbench visualizes the mapping on the CBM map by overlaying infrastructure items and/or organization structure on components. Then, the user can visually classify possible infrastructure shortfalls into several types. Typically, four types of opportunities tend to arise.

First, a gap indicates that a hot component does not have any infrastructure/organizational support. The enterprise may want to consider an infrastructure/organizational investment to improve the component's performance and support the intended business transformation. Second, a duplication indicates that a component is supported by multiple infrastructure items or multiple departments, possibly, deployed over time. The business may want to consolidate the applications to improve performance and reduce cost in communication and maintenance overhead. Third, a deficiency indicates that the current application lacks key functionality, or is poorly designed, and so incurs a project opportunity. Finally, an over-extension indicates that a system designed to support one business component is extended beyond its core capability to support others. Different definitions for the shortfall types may apply.

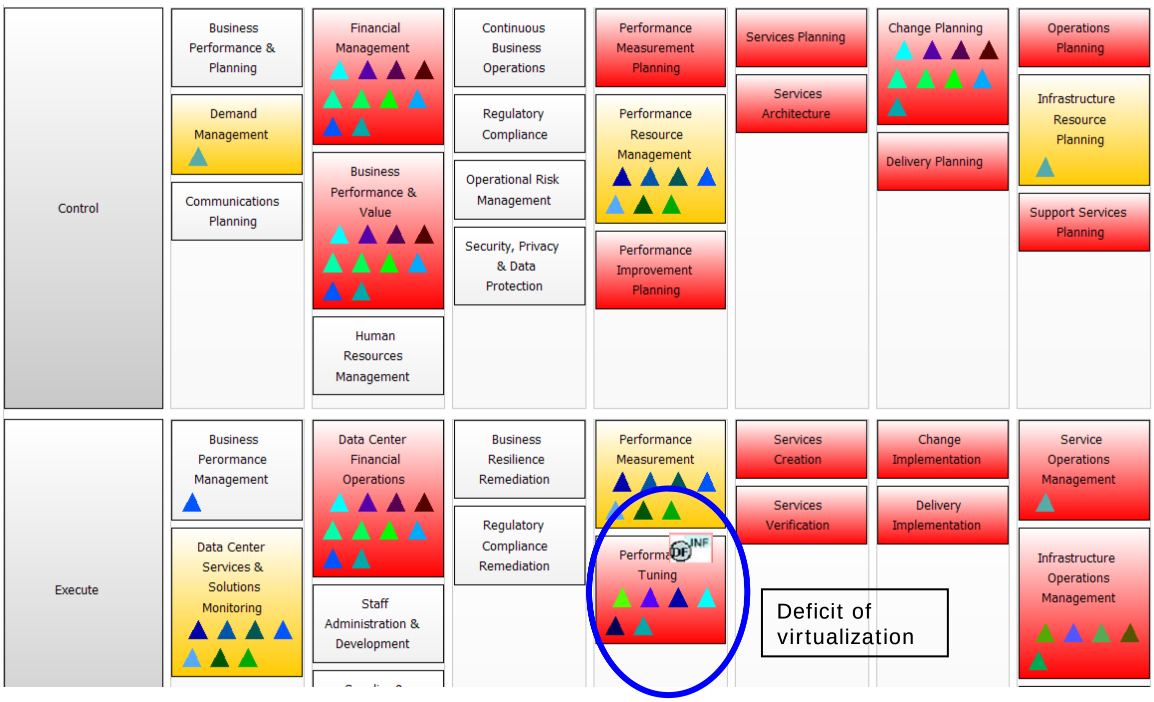

Figure 14: Landscape of infrastructure overlaid on component business map

The shortfall assessment is facilitated by an innovative visual overlay of information on business components. Figure 14 shows such an infrastructure overlay. It shows which infrastructure items implement the business functions of which business components. The triangles represent the infrastructure items and are color-coded with tool-tip showing the name of the item. In this example, the user can visually notice that six infrastructure items are supporting the 'Performance Tuning' component in ABC Inc. They are:

(a) CiRBA Solution
(b) Ecos Consulting and EPRI's Power Applications Center
(c) Energy Efficiency Rating
(d) IBM System Storage
(e) IBM Virtualization
(f) IBM Virtualization Engine TS7530 Server

The user can tell based on system performance that the low level of virtualization was implemented. This fact highlights an opportunity for virtualization. The user then can mark the Performance Tuning component having 'deficiency' in infrastructure. In the GT Workbench, this component is marked as a candidate for 'deficiency' shortfall. The noted shortfall is shown as 'DF^{inf}' to denote infrastructure shortfall on the Performance Tuning component in Figure 14.

Figure 15 shows which organizations implement the business functions of which business components. The squares represent the organizations and color-coded for different organizations. The user visually discover deficit in commissioning and retro commissioning in 'Infrastructure Operations Management' component. This fact highlights an opportunity for consolidation. The noted shortfall is shown as 'DF^{org}' to denote organization shortfall on the 'Infrastructure Operations Management' component.

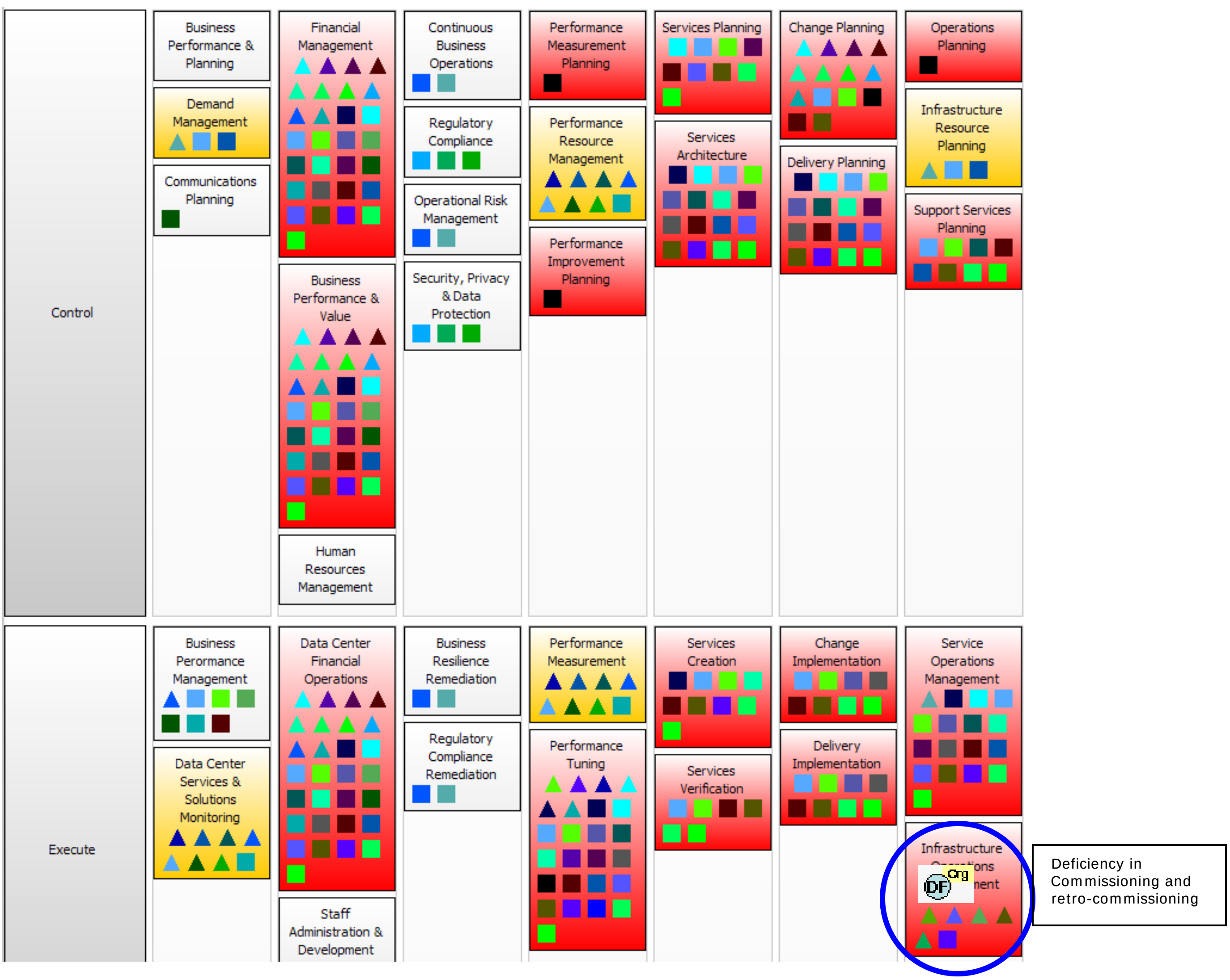

Figure 15: Landscape of organization overlaid on component business map

5.3. Solution Discovery

Once infrastructural/organizational shortfalls are identified and classified, one or more solution catalogs are used to identify transformation initiatives to address the shortfalls and support the intended business transformation. GT Workbench allows the user to explore the solution space to identify one or more solutions that may address one or more shortfalls of interest. The discovery of solutions for supporting components associated with a shortfall can be automatically conducted by executing the "Daisy-Chain" queries that correlate solutions and components by using their relationships to business processes. In addition, GT Workbench allows the user to manually correlate them, if desired.

The choice of solutions depends on a number of factors such as breadth of the pain points, the benefits offered by a solution, client's budget constraints, duration within which improved results are expected, etc. In this example, the solutions of 'Server Virtualization' and 'Commissioning and retro commissioning' were discovered to address the infrastructure and organizational shortfalls, respectively. Therefore, the user has chosen the solutions as potential candidate solutions for improving the 'Performance Tuning' and 'Infrastructure Operations Management' of ABC Inc.

Figure 16 shows the model linkages which lead to the selection of the solutions by using the daisy-chain analysis. Selecting a proposed solution or a set of proposed solutions in the GT Workbench shows the linkages of that solution with process, metrics and shortfalls. These linkages help us understand

(a) which processes the selected solution impacts (hopefully, positively),
(b) which metrics can be used to measure the impact of process improvements to be achievable by implementing the chosen solution, and
(c) which marked shortfalls the chosen solution will help with.

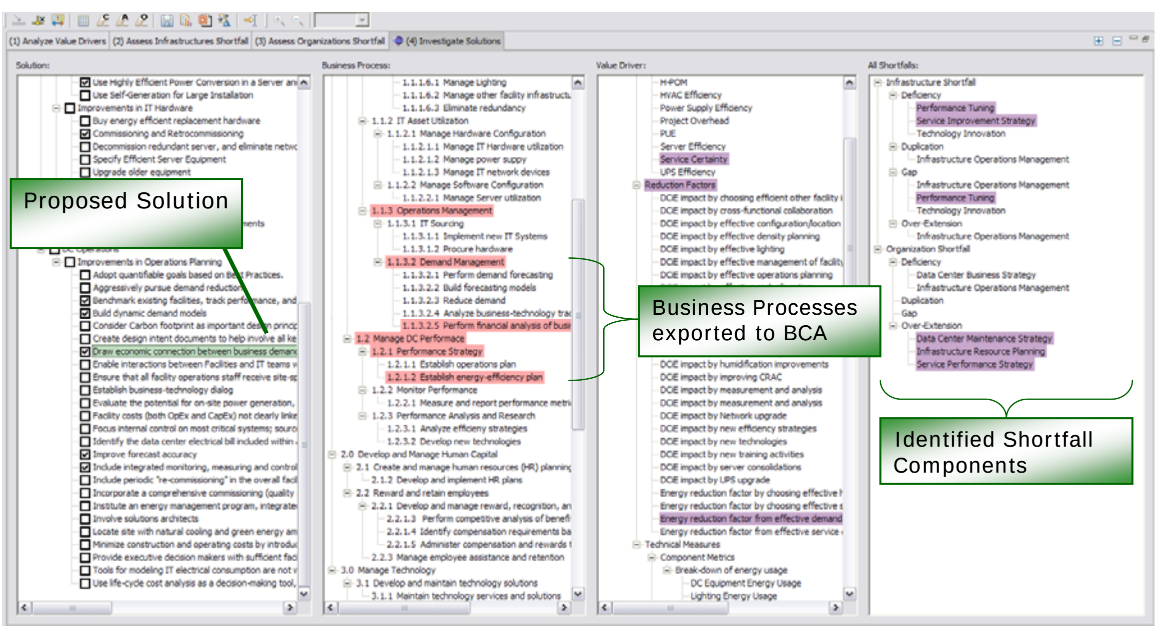

Figure 16: Solution analysis result

The solution analysis helps the GTW user get a quick idea at a qualitative level about which solutions can help address clients' shortfalls. The next step is to analyze the potential benefits the client can get by implementing the chosen solutions quantitatively. This business case analysis is done by clicking the 'Compute Business Value' button in the GT Workbench.

6. Green Business Case Analysis

Until now, using the GT Workbench, we have described how a consultant can identify opportunities for green transformation. The next step is to evaluate the recommended solutions to build business cases for them. The evaluation has to accurately model the potential benefits that can be achieved by implementing the recommended solutions while, at the same time, considering the costs and investments involved. GT Workbench provides a Green Business Case Calculator tool for this purpose. The GBCC tool standardizes the key input and output of a typical business case, and yet, allows flexibility for users to modify and add benefits and reports, making it easier to customize the application for the needs of a particular project.

When you click on 'Compute Business Value' button in the GT Workbench, the Green Business Case Calculator spreadsheet opens up with the 'Analysis Scope' tab in focus.

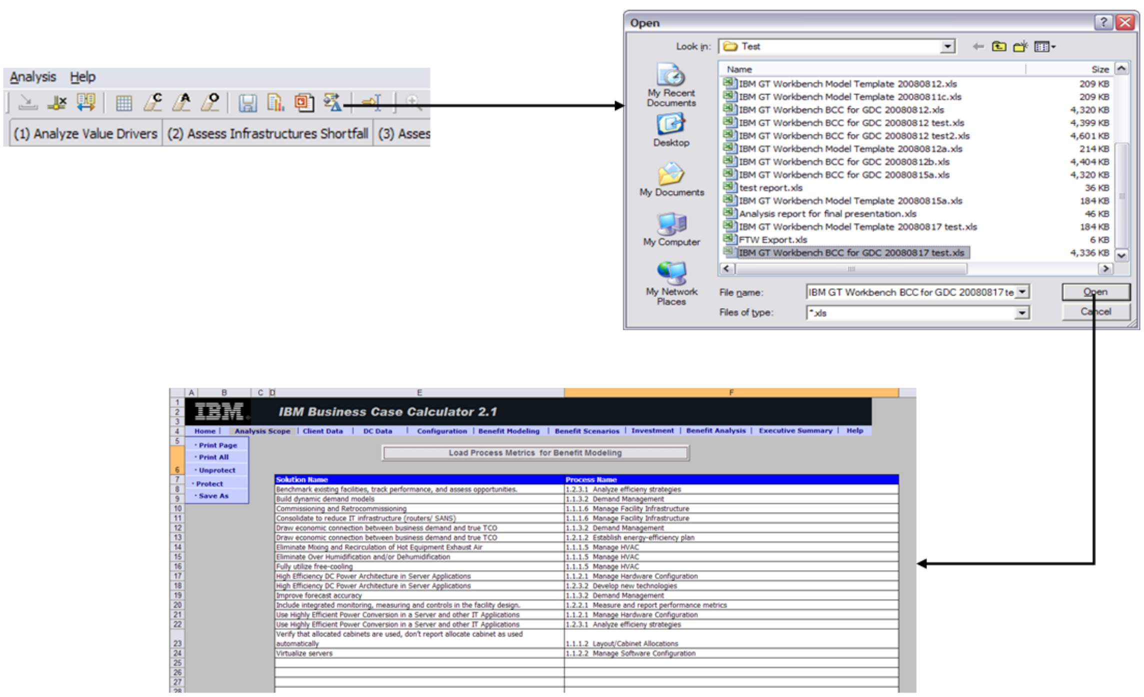

Figure 17: Exporting chosen set of solutions to the Green Business Case Calculator

The table in Analysis Scope has two columns: 'Solution Name' and 'Process Name'. The 'Solution Name' column refers to the name of the solutions that were chosen for analysis in the GT Workbench. The 'Process Name' column refers to the corresponding business processes that will be impacted as a result of improvements through the chosen solutions.

Solution Name	Process Name
Benchmark existing facilities, track performance, and assess opportunities.	1.2.3.1 Analyze efficieny strategies
Build dynamic demand models	1.1.3.2 Demand Management
Commissioning and Retrocommissioning	1.1.1.6 Manage Facility Infrastructure
Consolidate to reduce IT infrastructure (routers/ SANS)	1.1.1.6 Manage Facility Infrastructure
Draw economic connection between business demand and true TCO	1.1.3.2 Demand Management
Draw economic connection between business demand and true TCO	1.2.1.2 Establish energy-efficiency plan

Figure 18: Solutions exported to the Analysis Scope tab

6.1. Input Data

Before starting the impact analysis of the selected solutions on the bottom line, we need certain input data to perform the analysis. The Green Business Case Calculator guides the user to provide the types of input data it requires in a structured way through several worksheets which provide templates for the data. First, the Home page instructs the user to provide the project time frame and financial configuration for the analysis along with the basic company information, as shown in Figure 19.

Company	ABC Inc.
Geography	Americas
Industry	Data Center
	Proje
Expected start - year	2008
Forecast selection	Year
[illegible]	[illegible]
Number of periods	3

Project Financial Information	
Yearly Discount Rate	18.00%
Consider Terminal Value?	Yes
Growth Rate for TV calculation	2.00%

Figure 19: Input of basic company information and analysis time frame

Additionally, GBCC requires the annual revenues and energy consumption of the company to provide a base line profit and emission level for the analysis. There are various sources for carbon emission and they may be categorized as follows: *direct* sources (on-site combustion of fuels, e.g., boilers, business travel, company-owned vehicles) vs. *indirect* sources (off-site combustion of fuels (for use on-site), e.g., procured resources: electricity, materials and employee commute), *process* sources (on-site emission caused by processes) vs. *energy export* sources (on-site combustion of fuels for use off-site), and *upstream* sources (emissions caused by suppliers) vs. *downstream* sources (emissions created by an organization's products/activities during their lifecycle). In this study, we limit the carbon emissions to the energy consumption and focus on finding opportunities only for energy efficiency that reduce equivalent emissions. As shown in the Figure 20, GBCC collects the base line data only for the energy consumption.

Generic Inputs Input Description	Input Name	Input Value
Total annual revenue for the business entity. Reported on income statement.	Net Revenue	$13,000,000,000
Total annual energy consumption for Data Center business entity. Reported on electricity billing.	Energy Consumption	28,986,898 kWh
evaluation of components	Energy Consumption	28,986,898 kWh
Total annual carbon emissions for the business entity. Computed from annual energy utilization report.	Total Emissions in metric tons	23,189.52

Figure 20: Input of revenue, energy consumption and equivalent carbon emissions

Another input data GBCC requires is various technical metrics that are related to the key performance metrics discussed in the previous section. GBCC utilizes a simple Total Cost Ownership (TCO) model of the data center to instruct the user to provide this data. The goal of this data collection is to compute the base line performance of DCiE of the data center, which is supposed to be affected by selected set of solutions. The model consists of several categories as follows:

Hardware: This category computes the total annual electricity usage and energy costs, by taking into account the factors such as the number of IT hardware systems filled per rack, % of racks filled, % of racks in live service, % min of a rack to enable service, % compute utilization per rack; energy consumption of hardware, cooling and auxiliaries.

Electricity: This category compute total annual electricity usage and energy costs by taking into account the factors such as electricity price and indirect costs, energy distribution over IT and facility, loss factors for IT, cooling and auxiliaries.

Floor Usage: This category computes the total annual floor usage by taking into account the factors such as land costs, floor distribution for IT and facility.

Market: This category captures market interest rate, carbon emissions equivalent for energy, market price of carbon credit (CER), other miscellaneous costs and taxes; personnel costs for IT, Facilities, Maintenance and Security.

Financial: This category computes the total annualized costs with various distributions by taking into account the factors such as capital costs of IT and facility infrastructure and consolidates operating costs.

This information may be enhanced to capture more technical details to identify TCO in future so that a concrete benefit modeling can be done. Figures 21 and 21 show the input templates for the above information in GBCC.

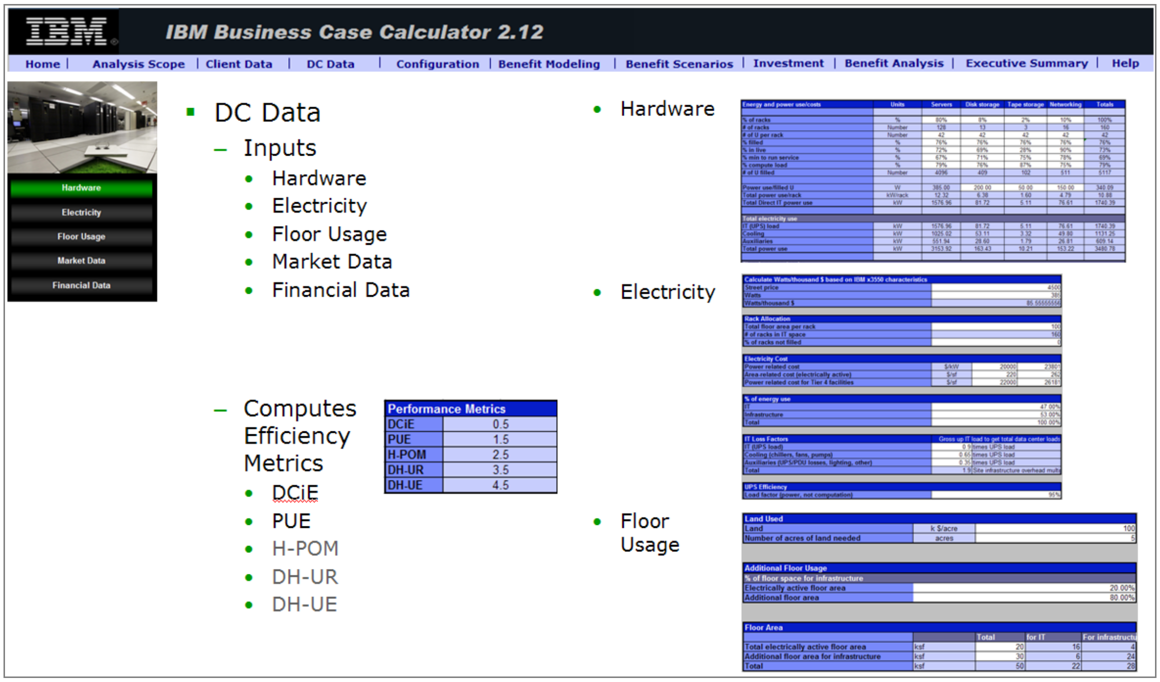

Figure 21: Data center data - Hardware, Electricty and Floor Usage

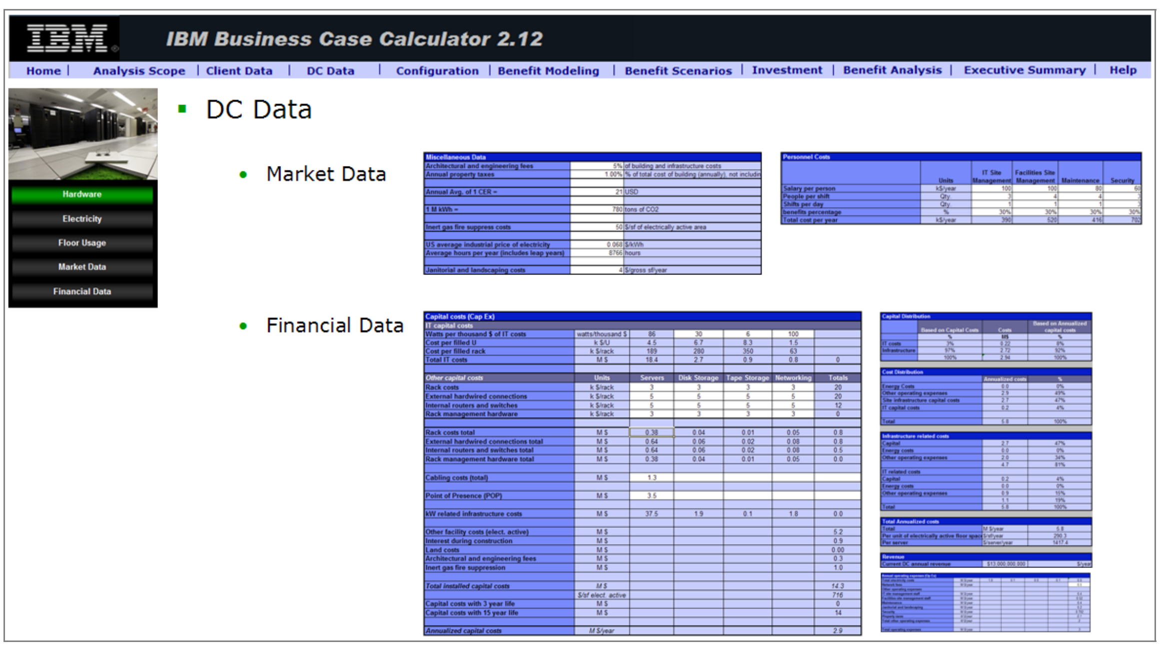

Figure 22: Data center data - Market and Financial Data

6.2. Business Case Analysis

Once all the input data is in place, the user can work on GBCC to conduct a business case analysis, which again takes a few steps. In this section, we present the computation of financial and carbon benefits of a particular solution, i.e., the implementation of the 'Virtualize Servers' solution, at ABC Inc., continuing our example from previous Sections. As noted earlier, the 'Performance Tuning' business component consists of the business process, Manage Software Configuration. This process is passed down to GBCC for the benefit computation. The GBCC tool automatically configures itself to capture the preliminary benefits for the process. Also, as noted earlier, this configuration is done by making a simple assumption that, if the clients' performance metrics are below the benchmark, then implementing the industry best-practice solution for the client would improve the metrics to the benchmark values. Therefore, the absolute difference between the as-is values for the client metrics for each of these processes and the benchmark values gives the expected savings in cost and carbon emission. A view of the benefit modeling is shown in Figure 23. It shows the business process that will be impacted by the implementation of the solution along with the performance metrics and their values.

Benefit description	Improvements in Software Configura					
Process Name	1.1.2.2 Manage Software Configuration					
Description of variables	Variable Type	AS IS case	Industry Median	Industry Benchmark	nprovement fact	TO BE case
Reduction Measures						
DCiE impact by effective server management	Value Driver	$0.00	$0.00	$0.30		$0.30
Technical Measures						
Efficiency and Quality Measures						
DCiE	Value Driver	0.49	$0.49	$0.55		0.55
Total energy benefit in the process '1.1.2.2 Manage Software Configuration'	Computed	28,986,898 kWh				22,297,614 kWh
Total carbon benefit in the process '1.1.2.2 Manage Software Configuration'	Computed	22,552 tons				17,348 tons
Total economic benefit for the process '1.1.2.2 Manage Software Configuration'	Computed	$1,971,109.08				$1,516,237.76
Indicate formula for total carbon benefit on AS IS and TO BE CASE - same		22,552 tons				17,348 tons
Total Carbon Flow impact of the benefit per period after 100% realized						5,204 tons
Indicate formula for total economic benefit on AS IS and TO BE CASE - same		$1,971,109.08				$1,516,237.76
Total Cash Flow impact of the benefit per period after 100% realized						$454,871.33
Description of the rationale behind the benefit, available benchmarks, sources of information and approach to quantfication						

Figure 23: A snapshot of benefit calculation

Once the total cost and carbon benefits are computed, they may be amortized over the period of financial analysis automatically by the GBCC tool as shown in Figure 25. The user can distribute the cost and carbon benefit realization independently over the analysis period. Additionally, the user can define the benefit category of the particular solution for consolidated analysis. Figure 24 shows a snapshot of a benefit scenario where the benefit is amortized over three years starting in 2008.

Benefit 16			Yearly value of benefit						Total Expected Benefit	
1.1.2.2 Manage Software Configuration			2008		2009		2010			
Total cost benefit Value at 100% per YEAR	$454,871.33		Cost	Carbon	Cost	Carbon	Cost	Carbon	Cost	Carbon
Benefit value and realization schedule - base case										
Total carbon benefit Value at 100% per YEAR	5,204 tons		60%	60%	90%	90%	100%	100%		
Benefit value and realization schedule - base case			272,922.8	3,122.6	409,384.2	4,683.8	454,871.3	5,204.3	1,137,178.3	13,010.7
Benefit estimated value range	Conservative scenario	75.00%	204,692.1	2,341.9	307,038.1	3,512.9	341,153.5	3,903.2	852,883.7	9,758.0
	Aggressive scenario	125.00%	341,153.5	3,903.2	511,730.2	5,854.8	568,589.2	6,505.3	1,421,472.9	16,263.3
Benefit realization per period - base case			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Benefit estimated value range	Conservative scenario	75.00%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Aggressive scenario	125.00%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Benefit Category	Virtualization		Comments on the benefit:							

Figure 24: A snapshot of a benefit scenario

Before a business case analysis based on the benefit calculation is created, GBCC requires the user to the define investment cost in different areas. Also, GBCC allows the user to tag the investments with categories and they facilitate the consolidated analysis. A view of the cost modeling in GBCC is shown in Figure 25.

Definition of level of detail on pricing						
Description of cost item	Solution Category	Type of cost item	2008	2009	2010	Total
Consolidation	Consolidation	Services	210,000.00	84,000.00	126,000.00	420,000.00
Virtualization	Virtualization	Software	210,000.00	42,000.00	84,000.00	336,000.00
HVAC	HVAC	Hardware	208,000.00	16,000.00	192,000.00	416,000.00
Business Planning	Business Planning	Consulting	56,000.00	27,000.00	34,000.00	117,000.00
Business Planning	Business Planning	Personnel	64,000.00	6,000.00	32,000.00	102,000.00
Rack Allocation	Rack Allocation	Hardware	96,000.00	16,000.00	32,000.00	144,000.00
Rack Allocation	Rack Allocation	Personnel	16,250.00	2,000.00	5,000.00	23,250.00
Analysis and Research	Analysis and Research	Consulting	91,000.00	14,000.00	35,000.00	140,000.00
Analysis and Research	Analysis and Research	Personnel	65,000.00	10,000.00	25,000.00	100,000.00
Measurement	Measurement	Hardware	176,000.00	48,000.00	96,000.00	320,000.00
Other Non-IT Infrastucture	Other Non-IT Infrastructure	Hardware	60,000.00	15,000.00	25,000.00	100,000.00
Other Non-IT Infrastucture	Other Non-IT Infrastructure	Personnel	25,000.00	25,000.00	25,000.00	75,000.00
Total recommendation additional costs			1,277,250.0	305,000.0	711,000.0	2,293,250.0
Ongoing Software Maintenance		0.05	10,500.0	2,100.0	4,200.0	16,800.0
Ongoing Hardware Maintenance		0.15	81,000.0	14,250.0	51,750.0	147,000.0

Figure 25: Cost model in GBCC

Once the costs and other client specific data are provided as input to the GBCC tool, it automatically computes the key financial and carbon metrics, and presents an executive summary with charts. An example financial analysis result is shown in Figure 26. It is a consolidated analysis showing both financial and carbon benefits.

Project Forecasted Cash Flow								
Description	2008		2009		2010		Total	
Benefit Details	Cost	Carbon	Cost	Carbon	Cost	Carbon	Cost	Carbon
1.1.1.2 Layout/Cabinet Allocations	154,260.71	1,764.92	231,391.07	2,647.39	257,101.18	2,941.54	642,752.96	7,353.85
1.1.1.5 Manage HVAC	126,714.16	1,449.76	190,071.23	2,174.64	211,190.26	2,416.27	527,975.65	6,040.66
1.1.1.6 Manage Facility Infrastructure	272,922.80	3,122.56	409,384.19	4,683.84	454,871.33	5,204.26	1,137,178.32	13,010.66
1.1.2.1 Manage Hardware Configuration	506,856.62	5,799.04	760,284.93	8,698.55	844,761.04	9,665.06	2,111,902.59	24,162.65
1.1.3.2 Demand Management	93,270.60	1,067.13	139,905.90	1,600.69	155,451.00	1,778.54	388,627.50	4,446.36
1.2.1.1 Establish operations plan	34,446.57	394.11	51,669.85	591.16	57,410.94	656.85	143,527.36	1,642.12
1.2.1.2 Establish energy-efficiency plan	34,446.57	394.11	51,669.85	591.16	57,410.94	656.85	143,527.36	1,642.12
1.2.2.1 Measure and report performance metrics	197,110.91	2,255.18	295,666.36	3,382.77	328,518.18	3,758.63	821,295.45	9,396.59
1.2.3.1 Analyze efficieny strategies	15,374.20	175.90	23,061.31	263.85	25,623.67	293.16	64,059.18	732.91
1.2.3.2 Develop new technologies	93,894.83	1,074.27	140,842.24	1,611.40	156,491.38	1,790.45	391,228.46	4,476.11
3.2.1.1 Manage IT Investments	424,546.57	4,857.31	636,819.86	7,285.97	707,577.62	8,095.52	1,768,944.05	20,238.80
3.2.1.2 Manage IT Services Delivery	8,447.76	96.65	12,671.65	144.98	14,079.61	161.09	35,199.02	402.72
3.2.1.3 Manage Facility Investments	97,651.28	1,117.25	146,476.91	1,675.87	162,752.13	1,862.08	406,880.32	4,655.19
3.2.5.1 Perform training	43,241.10	494.73	64,861.65	742.09	72,068.50	824.55	180,171.25	2,061.37
3.2.5.2 Engage cross-functional collaboration	68,157.45	779.80	102,236.18	1,169.70	113,595.76	1,299.67	283,989.39	3,249.17
1.1.2.2 Manage Software Configuration	272,922.80	3,122.56	409,384.19	4,683.84	454,871.33	5,204.26	1,137,178.32	13,010.66
Total Benefits	2,444,264.92	27,965.27	3,666,397.38	41,947.90	4,073,774.87	46,608.78	10,184,437.16	116,521.94
Cost Details								
Consolidation	210,000.0		84,000.0		126,000.0		**420,000.0**	
Virtualization	210,000.0		42,000.0		84,000.0		**336,000.0**	
HVAC	208,000.0		16,000.0		192,000.0		**416,000.0**	
Business Planning	56,000.0		27,000.0		34,000.0		**117,000.0**	
Business Planning	64,000.0		6,000.0		32,000.0		**102,000.0**	
Rack Allocation	96,000.0		16,000.0		32,000.0		**144,000.0**	
Rack Allocation	16,250.0		2,000.0		5,000.0		**23,250.0**	
Analysis and Research	91,000.0		14,000.0		35,000.0		**140,000.0**	
Analysis and Research	65,000.0		10,000.0		25,000.0		**100,000.0**	
Measurement	176,000.0		48,000.0		96,000.0		**320,000.0**	
Other Non-IT Infrastructure	60,000.0		15,000.0		25,000.0		**100,000.0**	
Other Non-IT Infrastructure	25,000.0		25,000.0		25,000.0		**75,000.0**	
Total Project Costs	(1,277,250.0)		(305,000.0)		(711,000.0)		(2,293,250.0)	
CF Totals								
Net projected cash flow from the project	1,167,014.9		3,361,397.4		3,362,774.9		7,891,187.2	
Terminal value					21,437,689.8		21,437,689.8	
Project final cash flows	1,167,014.9		3,361,397.4		24,800,464.6		29,328,876.9	
Overall Metrics								
Financial			Carbon					
Net present Value without terminal value - NPV	5,449,788		Total Carbon Reduction			%	172%	
Net present value considering terminal value - NPV (1)	18,497,427		Internal Cost of Carbon			$/ton	19.68	
Internal Rate of Return - IRR	N/A							
Return on Investment - ROI	344.10%							

Figure 26: Consolidated financial and carbon analysis: cash and carbon flow forecast

The financial benefits are represented by using standard cash flow metrics such as *Net present value* (NPV), *Internal Rate of Return* (IRR), *Return On Investment* (ROI), and *Payback period. Net present value* (NPV) is a standard method for the financial appraisal of long-term projects [17]. It measures the excess or shortfall of cash flows, in present value (PV) terms, once financing charges are met. NPV is formally defined as present value of net cash flows when each cash inflow/outflow is discounted back to its PV:

$$\mathrm{NPV} = \sum_{t=0}^{n} \frac{C_t}{(1+r)^t}$$

Where t is the time of the cash flow, n is the total time of the project, r is the discount rate, and C_t is the net cash flow (the amount of cash) at time t. NPV is an indicator of how much value an investment or project adds to the value of the company. With a particular project, if C_t is a positive value, the project is in the status of discounted cash inflow in the time of t. If C_t is a negative value, the project is in the status of discounted cash outflow in the time of t. Generally speaking, companies will accept appropriately risked projects with a positive NPV.

Internal Rate of Return (IRR) is a finance metric used by businesses to decide whether they should make investments [17]. It is an indicator of the efficiency of an investment (as opposed to NPV, which indicates value or magnitude). IRR is the annualized effective compounded return rate which can be earned on the invested capital, i.e., the yield on the investment. A project is a good investment proposition if its IRR is greater than the rate of return that could be earned by alternative investments (investing in other projects, buying bonds, even putting the money in a bank account). Thus, IRR should be compared to an alternative cost of capital including an appropriate risk premium. In general, if IRR is greater than the project's cost of capital, or hurdle rate, the project will add value for the company.

Return On Investment (ROI) or *Rate Of Return* (ROR) is the ratio of money gained or lost on an investment relative to the amount of money invested [17]. ROI is usually given as a percent rather than decimal value. ROI does not indicate how long an investment is held. However, ROI is most often stated as an annual or annualized rate of return, and it is most often stated for a calendar or fiscal year.

Payback period refers to the period of time required for the return on an investment to repay the sum of the original investment [17]. It is intuitively the measure that describes how long something takes to pay for itself: shorter payback periods are obviously preferable to longer payback periods (all else being equal). Payback period is widely used due to its ease of use.

GBCC counters the financial metrics' by introducing a number of carbon metrics for "carbon flow" analysis. *Carbon Reduction On Investment* (CROI) is the % reduction in carbon emissions from all the investments considered for analysis. CROI is usually given as a percentage rather than a decimal value. CROI does not indicate how long an investment is held. However, CROI is most often stated as an annual or annualized rate of return, and it is most often stated for a calendar or fiscal year.

Internal Cost of Carbon (ICC) is a new carbon metric useful to decide whether they should make an investment. It is an indicator of the efficiency of an investment (as opposed to CROI, which indicates the value or magnitude), which is comparable to market price of carbon credit (CER). ICC is the ratio of total cost of a green investment to the total carbon emission reduction predicted over the analysis period. A project is a good investment proposition if its ICC is lesser than the market price of carbon that could be earned by purchasing Certified Emission Credits (CER). Thus, ICC should be compared to the CER value including an appropriate risk premium. In general, if the market value of emissions reduced from an investment is lesser than the project's cost of capital, the project will add value for the company.

In the cash and carbon flow forecast in the consolidated financial and carbon analysis shown below in Figure 27, the result indicates that the project will yield a significant cost and carbon reduction. The Return on Investment (ROI) is projected as over 300% and the Carbon Reduction on Investments (CROI) is more than 150%. Note that the Internal Cost of Carbon (ICC) is below $20 compared to the market price of $21. Over next 3 years, this denotes that going green by the internal investments is cheaper than buying Carbon Credits for emissions compliance and it brings significant cost savings as well.

Finally, GBCC generates executive summary reports out of the consolidated financial and carbon analysis results. Figure 28 shows the reports on the financial benefits graphically showing the results in the total benefits, costs, NPV, ROI, IRR, costs by category, and breakeven point.

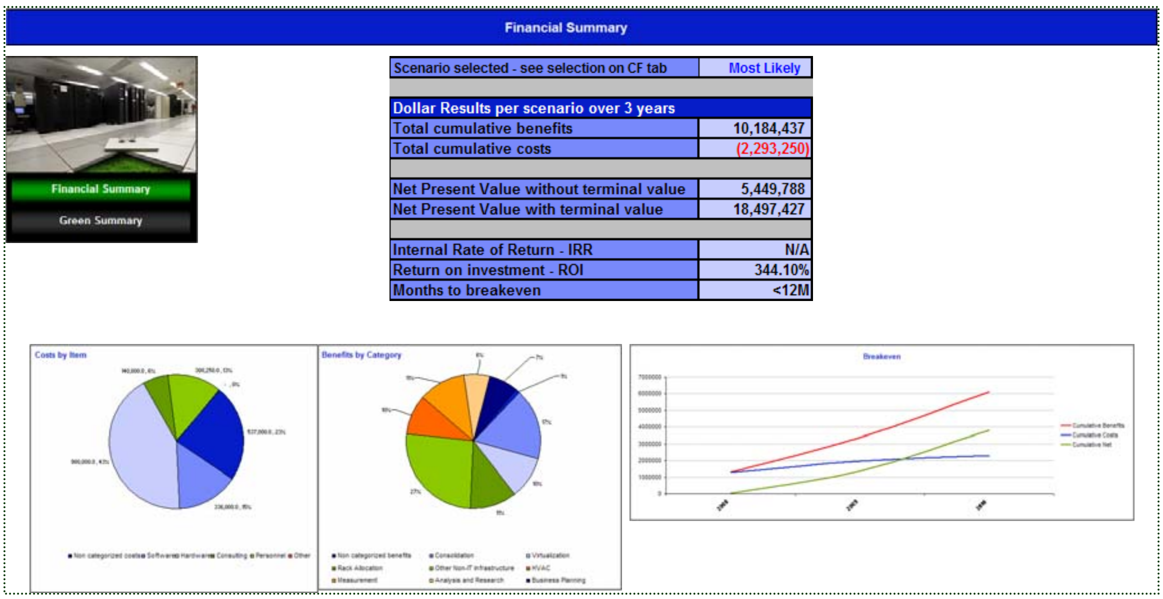

Figure 27: Executive summary report on financial results

Figure 28 shows the reports on the financial benefits graphically showing the results in the emission reduction tons/year, Internal Cost of Carbon, and Carbon Reduction on Investment.

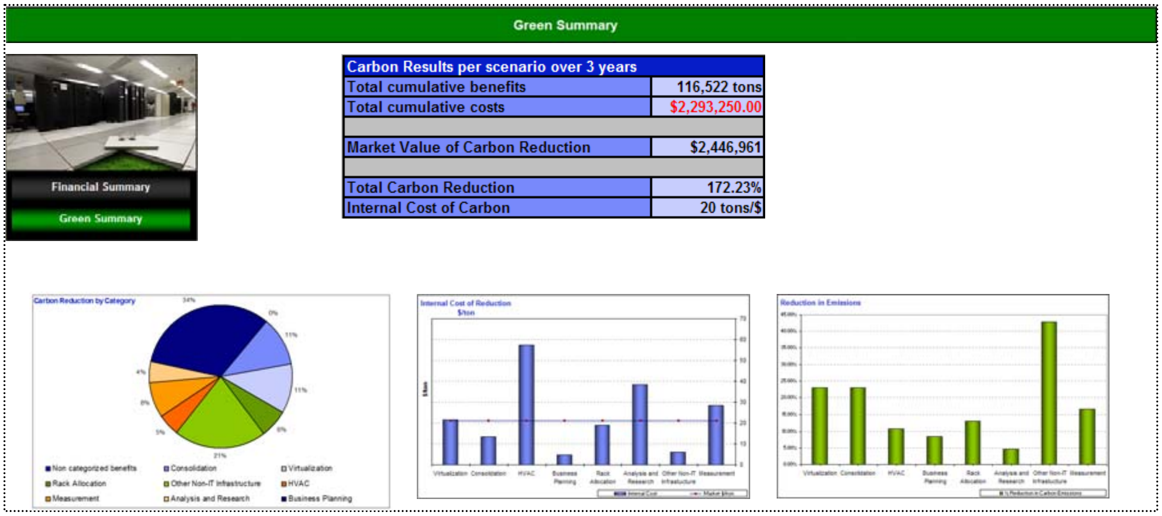

Figure 28: Executive summary report on green results

7. Discussion and Future Work

As in most of other studies in the green aspect of data centers, this study used the energy consumption (in kWh) as a carbon emission (in CO2) equivalent. One way to extend the study would be directly considering sources of energy such as hydro, gas, clean energy, etc. EPA provides a guideline for conversion between energy consumption and carbon emission [4]. When the sources of energy are considered, the emission equivalent often varies significantly, and so does the entire carbon flow analysis. This study provided carbon emission from sources other than energy consumption in Section 6.1. Also, it provided a set of value drivers with carbon emission at an operational level from the sources stated in Section 6.1. An extended and concrete model for data center carbon emission in our future work would include both computation of carbon emission and a benefit model coupled with low-level technical metrics from the value drivers presented with hardware, electricity, floor usage, market and financial data as presented in Section 6.1.

Another direction to extend the present work would be carbon portfolio management based on the green transformation diagnosis and green business case analysis capabilities in real-time. The carbon portfolio management will provide an enterprise-level integrated view for dynamically assess, analyze and report on carbon emissions over all business lines. Real-time monitoring of carbon emission associated with carbon portfolio management will facilitate a number of dynamic applications:

- Agile alignment of business units for enterprise-level green strategies by monitoring the business' CER position in real-time and reflect it to its business model. The real-time data will support more accurate and dynamic decision support. An end-to-end integration can witness continuous green business transformation initiatives to be effective in every moment and activity.
- Optimization to reach the target level of carbon emission and to find a low cost, low market risk (induced from CER value), and low emission strategy. A third party data source for market value of CER and other parameters affecting it can be integrated to the

optimization. The result would provide an enterprise-level strategy to invest in carbon markets against internal green initiatives.

- Dynamic pricing model for business stakeholders based on its CER position and unrealized carbon benefits from outstanding green investments to maximize the revenue out of deals and investments.

8. Concluding Remarks

In this paper, we introduce the Green Transformation Workbench, a consulting practitioner's tool for identifying and analyzing green transformation opportunities. It embodies structured analytical models (both qualitative and quantitative) to enhance the consultants' practices. The tool helps visualize the linkages of various enterprise models such as component business models, business process models, value driver models, organization models, infrastructure models, and solution models. Using this tool, consultants can examine which operational functions and business components are underperforming in comparison to industry benchmark measures and why. By investigating the organizational responsibilities and infrastructure portfolio in conjunction with business components, shortfalls such as duplications, over-extensions, gaps and deficiencies can be identified and reasoned. Following that, specific solutions can be discovered to address the identified shortfalls. Financial and carbon benefits of implementing specific solutions can be analyzed further via conducting a green business case analysis. We have conducted an empirical study with the Green Transformation Workbench by using data sets obtained from a number of enterprise data center services.

The GT Workbench methodology and its software solution is part of an ongoing research initiative on green design and transformation at IBM Research and Global Business Service Divisions. With a methodology and a research prototype in place, we work with practitioners to validate them with real-world green transformation initiatives. In addition to the tool and methodology, in practice, the availability of useful and accurate content and information of business components, value drivers, processes and solutions is critical to meaningful analyses. Further validation results from practices will be reported in the future.

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