https://doi.org/10.48009/3_iis_2017_195-205

Issues in Information Systems
Volume 18, Issue 3, pp. 195-205, 2017

DATA VISUALIZATION: A CASE STUDY IN RENEWABLE ENERGY

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ABSRACT

This paper uses data visualization tools based on Dashboard and the Balanced Scorecard to assess the eco- and cost-efficiency of renewable energy based bio-fuels. It also intends to help increase the public awareness of renewable energy and facilitate the commercialization of renewable energy. Furthermore, this paper evaluates the effectiveness, the level of user involvement, and usability of two data visualization tools. Based on the case study, this paper demonstrates how effective and useful both the Dashboard and the Balanced Scorecard are in communicating the strategic goals toward sustainability and thus provides easier guidelines for renewable energy development decisions and communicating the benefits of renewable energy development across the energy industry.

Keywords: Sustainability, Data Visualization, Renewable Energy, Business Intelligence

INTRODUCTION

The International Energy Outlook 2016 (IEO2016) report forecasted a significant growth in worldwide energy demand over the 28-year period from 2012 to 2040. Total world-wide consumption of energy is expected to grow from 549 quadrillion British thermal units (Btu) in 2012 to 629 quadrillion Btu by 2020 and to 815 quadrillion Btu by 2040—a 48% rise from 2012 to 2040 (EIA, 2016). This rapid growth of energy demand cannot be filled by traditional fossil fuels such as oil, natural gas, and coal. Rationale being that these conventional energy sources have been dwindling and creating adverse environmental conditions though pollution resultant from carbon emissions and natural habitat destructions during their extraction.

Examples of alternative energy sources include nuclear, solar, hydro, wind, geothermal, and biomass energies. With the exception of nuclear energy, these alternative sources provide clean, non-toxic, and renewable energy which are environment-friendly. However, many of these sources fail to completely replace fossil fuels and satisfy growing energy demands. A lack of clean energy use is attributed to its limited technology for commercialization failures. For instance, bio-fuel has been regarded as one of the viable sources of renewable energy. Despite the aforementioned merits, generation of bio-fuel poses one major challenge associated with complicated fuel production and commercialization processes. Considering such a challenge, this paper aims to improve bio-fuel production and commercialization processes by utilizing Dashboard and Balanced Scorecard based monitoring prototypes. These prototypes are built upon the concept of Business Intelligence (BI) supported by a strategy map that can help bio-fuel developers better understand the true positive impacts of bio-fuel.This paper focuses on the analysis of various ways to produce bio-fuel created from microalgae and fine-tune those ways so as to produce bio-fuel on a commercial scale at an affordable price.

RELEVANT LITERATURE

Microalgae based bio-fuel is one of most promising renewable energy sources as microalgae do not require cultivable land and clean water, tend to grow faster than crop plants, have biomass productivity estimated to be 50 times more than the fastest growing terrestrial plant such as switchgrass, and are far more efficient than crop plants in terms of converting sunlight into oil (Chisti, 2007; Li, et al., 2008). Furthermore, microalgae can convert carbon dioxide to potential biofuels and are easier and less costly to clean and refresh in case of contamination. Despite the

aforementioned merits, generation of biofuel from the microalgae poses one major challenge associated with complicated fuel production and commercialization processes.
Though still scarce, a vast majority of prior literature focused on the identification of various input parameters that can significantly affect the volume and cost of bio-fuel production. Borowitzka (1992) is one of the first to find the functional relationship between the algae growth (volume of production) and the cost of bio-fuel production. In particular, a decrease in the annual algae growth period - a number of days in a year when the environmental conditions are in favor of algae growth – a decrease from 300 to 250 days can increase the cost by 33%. Ma (1999) found that a cost could be reduced by continuously running the transesterification process, shortening the reaction time, and increasing the production capacity. He also noted that the cost and volume were dependent on the quality of microalgae supplied. Later, Chisti (2007) discovered that the algae growth rate and the oil content of the biomass could dictate the oil productivity that represented the mass of oil produced per unit volume of the microalgal broth per day. Pienkos and Darzins (2009) observed that the biomass was reduced in the absence of sunlight because of respiration and the rate of respiration depended on sunlight intensity during growth, temperature during growth, and temperature during the night. They also noticed that, in the case of small and medium scale production, productivity as well as cultivation cost was higher in controlled environments (e.g., photo-bioreactor). In the case of large scale production, they learned that a lack of sunlight limited the yield to a maximum of $100gm^{-2}$ day^{-1}. In addition, they found that particular harvesting methods such as centrifugation, flotation, filtering, micro screening, gravity settling, and flocculation affected the cost. The other factors which affected the harvesting cost were the cultivation process.

As the prior literature reveals, there are many research gaps to be filled. To elaborate, improvements in the bio-refinery process and advances in photo-bioreactor engineering are required to reduce the cost of production. More importantly, prior research so far has failed to provide detailed evaluations of the algae cultivation process (e.g., mixing, optimal cultivation scale, heating/cooling, evaporation, O_2 build-up, and CO_2 administration) and its true cost impact. Such process can be tied to the potential improvement of land utilization and yield.

To fill the aforementioned research gaps left by prior research, this paper is intended to propose data visual tools and adopt them to systematically assess the impact of various bio-fuel production processes on both the cost and volume of bio-fuel production, while evaluating the commercialization potential of algae as a viable alternative energy source.

Data visualization is designed to decode and present complex (big) data in a pictorial or graphical format and thus enables the decision maker to grasp difficult and esoteric concepts/ideas with more clarity. Its underlying philosophy is "a picture is worth a thousand words." Examples of data visualization tools include Tableau, Google charts, Datawrapper, Dygrapgh, Raw, Timeline JS, Infogram, Plotly, ChartBlocks, and so forth. Among these tools, data visualization tools that are intended for performance evaluation and suitable for outcome assessment are the balanced scorecard (BSC) and the dashboard (Lea, 2011). BSC was introduced by Kaplan and Norton (1992) to supplement traditional financial measures with criteria that measure business performance from three additional perspectives: customers, internal business processes, and innovation and learning (Min, 2015). It also links the organization's operational plans and budgets, supports continuous performance monitoring and plan adjustments, while ensuring that every decision maker has the most up-to-date information and analyses at their fingertips (DeBusk, et al., 2003; Andonov-Acev D., et al., 2008).

Another alternative visualization tool which is intended for performance evaluation is a dashboard. A dashboard offers graphical diagnostic capability complete with colorful graphical indicators and easy-to-read gauges and thus can help the organization monitor its progress and identify when it must change direction to improve its performance (Min, 2015). The degree of details in a dashboard can vary depending on particular business requirements, and the usefulness of a dashboard is dependent on its underlying database software (Marcus, 2006; DeBusk, et al., 2003; Pauwels, et al., 2009).

RESEARCH METHODOLOGY

To improve adaptability in this pilot study, the researchers work with a biofuel research lab located in Taiwan to better understand and model various issues considered in microalgae production processes. Microalgal sampling and screening were conducted on the costal line of Kaohsiung, Taiwan. Figure 1 shows various stages of the biofuel project

that were presented to and observed by the researchers in field visits throughout the research period.
We employ data visualization tools to evaluate the extent of impact of various bio-fuel production alternatives on commercialization potentials in terms of their cost and volume. The current bio-fuel production process is not yet matured. To compete with the fossil fuel in terms of affordability and demand, the process needs to be perfected. Thus, the process needs to be constantly evaluated from different perspectives and at different levels until it reaches perfection. For such evaluation, the proposed dashboard was used to pinpoint various issues and concerns associated with the current process, as it can respond to the increasing complexity and diversity of market conditions to be handled by the senior management. The dashboard focuses on operational and tactical aspects by monitoring the core operational processes that drive the business on a day to day basis, whereas the BSC focuses on strategic aspect by charting the progress towards achieving long-term goals. More specifically, since the traditional four BSC perspectives do not reflect the bio-fuel commercialization assessment, we introduce the four modified BSC perspectives shown in Figure 2. Herein, the financial perspective reflects the stakeholders' (e.g., investors') points of view regarding the profitability of bio-fuel production and commercialization. The Business Processes perspective aims at monitoring and achieving short term bio-fuel production targets. The sustainability perspective measures the progress towards achieving cleaner environments and resource conservation. The innovation perspective will prepare the organization for future with continuous research and development (R&D) efforts for more efficient bio-fuel production.

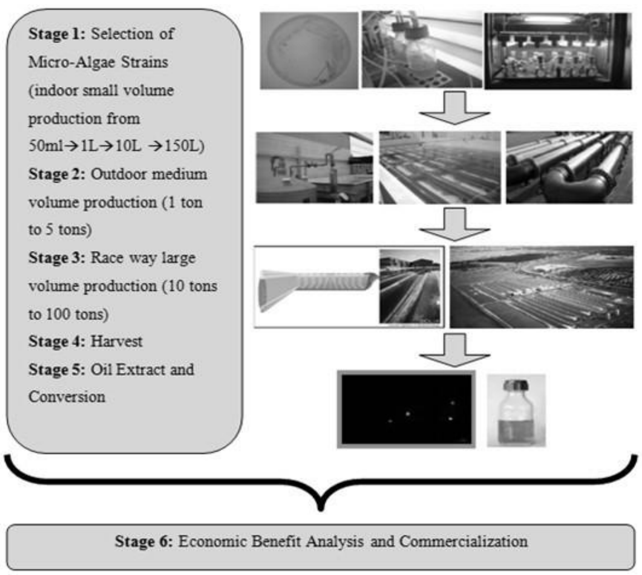

Figure 1. Case Biofuel Production and Harvest Stages
(Data Source: Huang, C. C., Chen, C. N., and Lee, T. M. (2010) Microalgal Biodiesel Development Team, National Sun Yat-sen University, Taiwan)

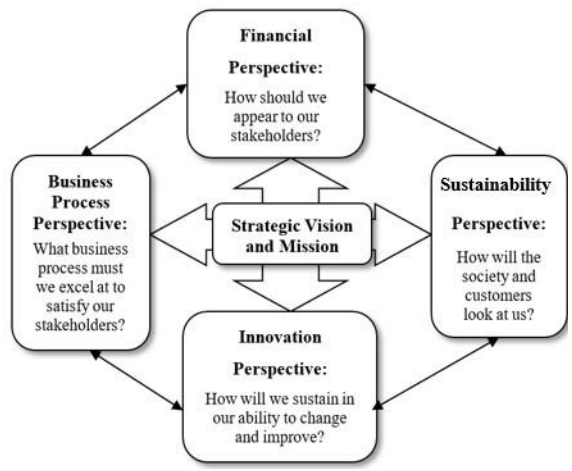

Figure 2. Four Perspectives of the BSC

The Development and Application of Dashboard and Balanced Scorecard (BSC) Prototypes

Through discussion with the research team, literature research, and field observations, the main objective of the visualization prototypes was set to "Provide Sustainable Fuel Alternative" and was operationalized through three business strategies as *Production Improvement strategy*, *Profitability Improvement strategy*, and *Providing Environmentally Friendly Product strategy*. Objectives and KPIs were then derived for each of four BSC perspectives using the same process. Table 1 provides the strategy, objectives, and KPIs hierarchy for the Business Process perspective as an example and will be used to illustrate the dashboard prototype and BSC prototype in the later sections.

We developed the prototypes of both dashboards and BSC and then implemented them using software tools provided by SAP. Each prototype has a front-end tool which presents the data to the users and a back-end tool which stores the data and queries in the required form. The dashboard was implemented using the SAP Business Objects Dashboard Designer (a.k.a., Xcelsius) and the frontend of the BSC was implemented using SAP SEM module. Both dashboard and BSC prototypes are drawing data through a data warehouse constructed using SAP BI 7.0.

Table 1. Strategy, Objective, and KPI Hierarchy for the Business Process Perspective

Strategy 1	Objective	KPI / Measure
Production Improvement	Improve harvest process efficiency	Harvest efficiency
		Harvest rate
	Improve the cultivation process	Cultivation efficiency
	Improve the fuel production process 2	Production efficiency/ 3
		Biofuel cycle time
		Oil Extraction Rate
	Select Suitable Algae Strains	No. of algae strains tested
	Reduce contamination rate	Contamination Rate
	...	...
Profitability Improvement	Improve External Growth Environment	Profit margin – External
		Capacity utilization of outdoor algae growth equipment
		Anual growth period
	Improve Internal Growth Environment	Capacity utilization of indoor algae growth equipment
		Anual growth period
	Creative marketing process	Marketing Efficiency Ratio
Provide Environmental Friendly Products	Improve water quality	Volume of water cleaned
	Reduce Environment Pollution	CO_2 Reduction rate
		SO_2 Reduction rate

Data Collection

Availability of data is very important for a Performance Management and Monitoring system. During the KPI identification process, we worked with the bio-fuel research team, conducted field observations, and referenced literature to ensure that the data for the KPIs are representative, adequate, and available or feasible for data gathering. Experiment factors and data recorded during various experiments were used along with some simulated data for prototype development. The simulated data was generated due to time constraints. The prototype validation was done through a survey which was aimed at gaining insight into the effectiveness, efficiency and usability of the proposed prototypes. The survey respondents were primarily researchers and scientists involved in the R&D of bio-fuels. The survey contained three sections namely Demographic, Dashboard and Scorecard section. The questions in the demographic section were intended for gaining insight into the background of the survey respondents.

Dashboard Prototype Design

The case dashboard prototype is to have a user-friendly and intuitive interface to improve accessibility that allows users to have easy access to information and services, taking into account their different requirements. Some design principles utilized in this study are summarized below.

- Information categorization: Information is broken down into different tabs, which are organized into a meaningful order and hierarchy, denoted as A and B in Figure 3.
- Use of consistent and common charts and diagrams: The dashboard is easy to operate because it uses graphs and dials, clickable charts, geographic map, and clearly labeled sections, as in the example shown in Figure 3 and Figure 4.
- Dynamic information tip: Placing the cursor over the state gives the statistics for that state, as in the example shown in label H in Figure 3.
- Utilizing familiar selector such as radio button or drop-down menus to select a desired object as shown in Figure 3 and Figure 4.

The dashboard screen provides navigation structure, performance overview, and detailed drill-down ad-hoc analysis. In general, the four BSC perspectives and strategies are used as navigation guide on the top of a dashboard screen denoted as A and B on Figure 3. For example, the "Production Improvement" strategy is denoted as 1 in Table 1 is one of Business Process Strategies and was visualized as the "Production" tab denoted as C on Figure 3.

Below the navigation structure, the dashboard screen was divided into two parts where the upper part contains a summary of various KPIs and the lower half provides detailed guided drilldown or ad-hoc analysis. This particular division saves user time as it provides a quick glimpse of the performance from the upper half of the screen and also provides the detailed information about KPIs, when the user wants to further analyze the performance. Figure 3 shows the initial "Business Process" screen, the upper left area of the dashboard screen denoted as D is the visualization of objectives and KPIs denoted as 2 and 3 from Table 2 to provide a performance summary at a glance through the use of visual components such as gadgets and texts. To improve usability, the upper right area denoted as E provides the formula for score calculation. It is evident that the overall score is dependent on the weighted score of Cultivation Process, Harvest Process, and Fuel Production Process (i.e., 79.88 = 0.2 x 85 + 0.4 x 78 + 0.4 x 79.2). The individual process score is determined by its KPI. For example, the Harvest Process is measured by weighted Harvest Efficiency KPI score and Harvest Rate KPI score (i.e., 78 = 0.6 x 80 + 0.4 x 75)

In general, the lower half of a dashboard screen contains the guided analysis of each of dependent KPIs that provides detailed drill-down ad-hoc analysis. Area F on Figure 3 are a list of KPI choices taken from Table 2 (denoted as 3). Once a KPI is selected (e.g., Cultivation Efficiency in this case), the trend chart is displayed for both actual value and target value (denoted as G on Figure 3). The dashboard also allows a user to select a specific time frame using a slider for analysis and causal-relationship diagnosis (denoted as H on Figure 3).

Figure 4 shows "Sustainability" perspective as another dashboard design example to show the design consistency and usability.

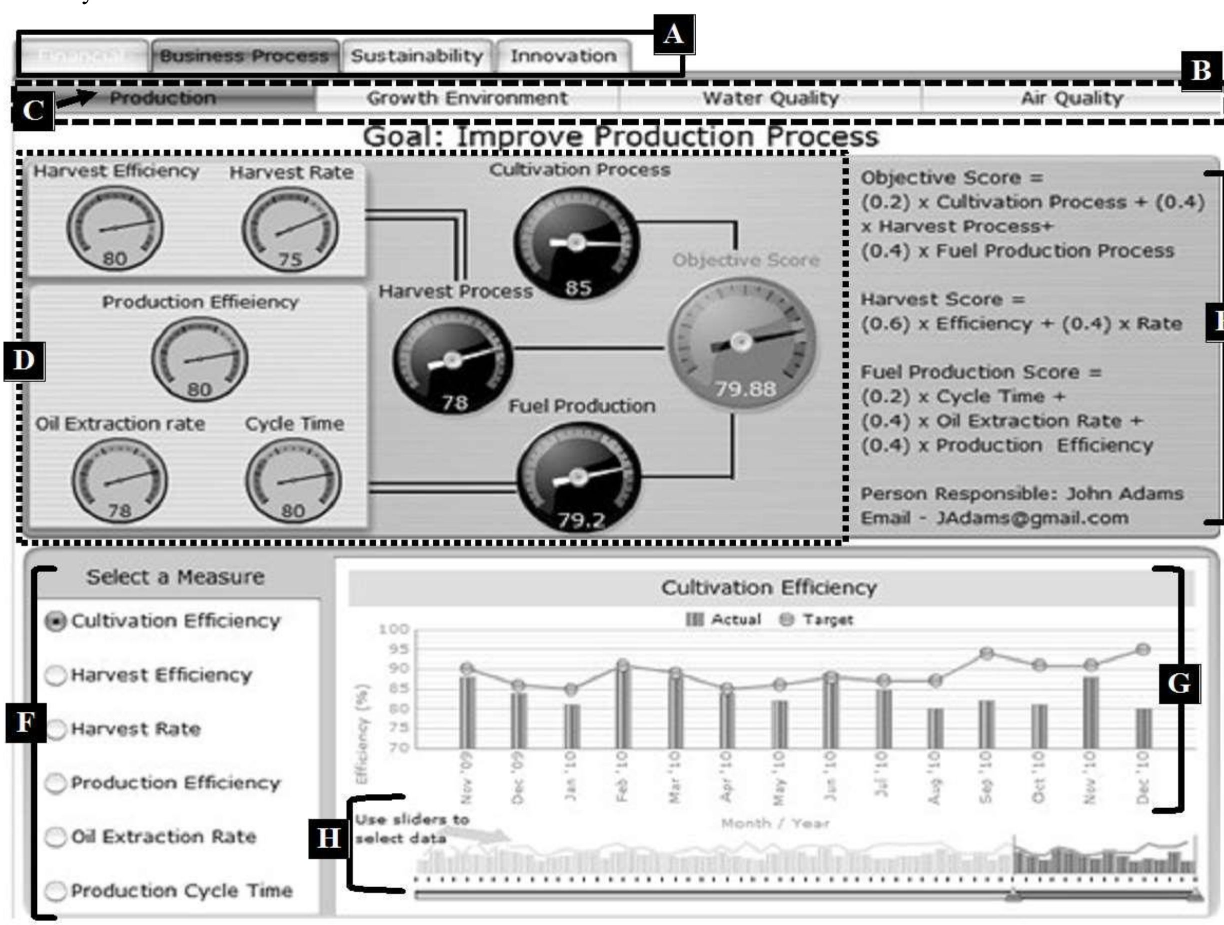

Figure 3. Dashboard Design Example: Business Process Perspective

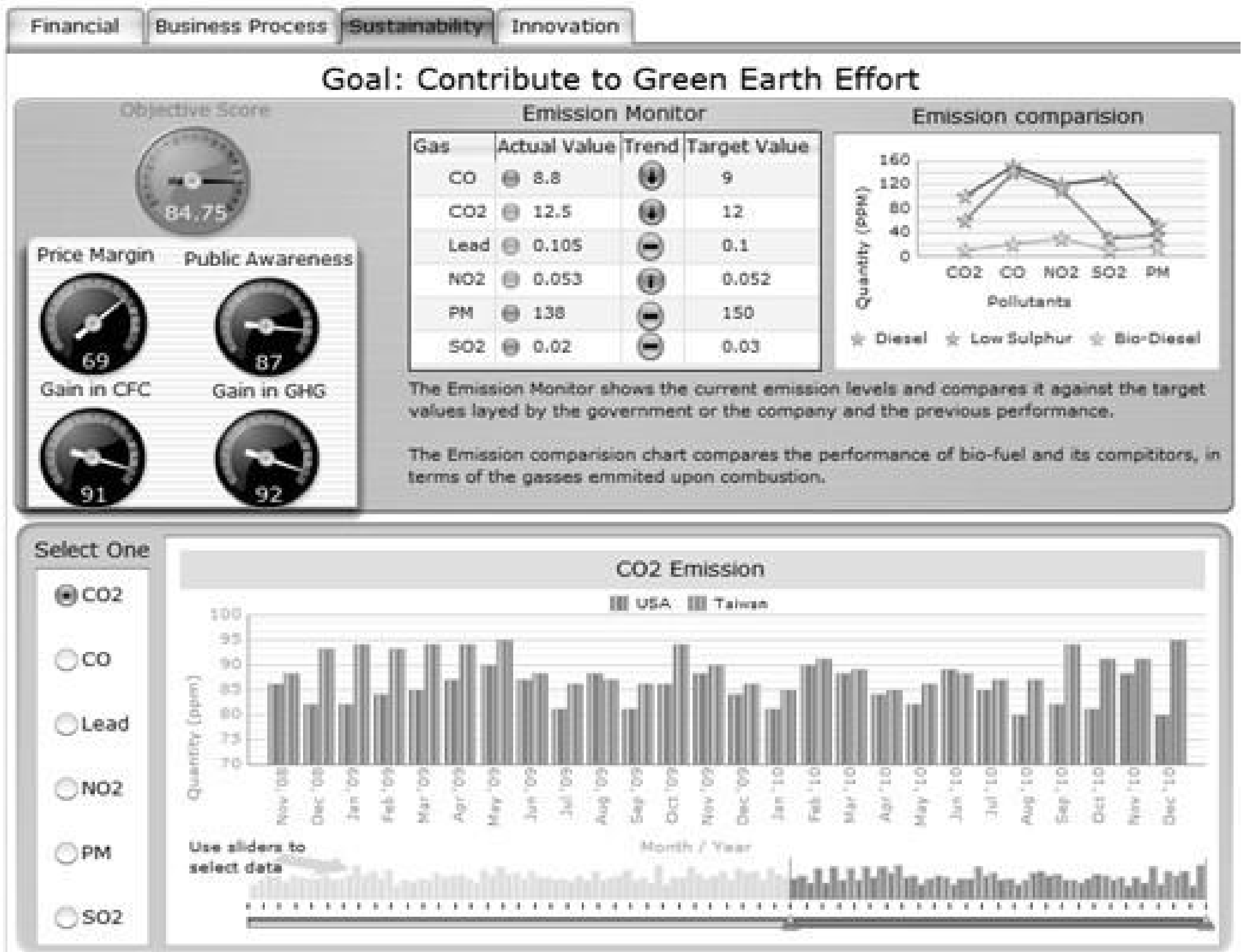

Figure 4. Dashboard Design Example 2: Sustainability Perspective

Balanced Scorecard (BSC) Prototype Design

The same dashboard design principles were used to develop Balanced Scorecard (BSC) prototype. The Perspective, strategies, objectives, and KPIs are similar to those used in the dashboards with a well-defined cause-effect strategy map. Figure 5 shows a partial strategy map that we developed with the research team, literature review, and field observations.

The scorecard initial screen, as shown in Figure 6, the navigation structure is provided on the top (denoted as A1 in Figure 6) and the prototype provides the user with a quick glimpse of how well the organization has been performing, through graphical indicators. This initial screen allows the user to view the meaning of graphical indicators (denoted as B1 in Figure 6), and changes in the time period of evaluation and changes in the way the data is represented (denoted as C1 in Figure 6). The data are displayed as perspectives, objectives, and measures/KPI hierarchy ((denoted as D1 and E1 in Figure 6). The user can drilldown to any level of detail for analysis as his/her desire by double clicking on a measure/KPI as denoted as G1 in Figure 6.

The measure in a scorecard provides the most detailed level of information. The BSC prototype shows additional details provided at the measure level in addition to allows the user to view the same data in multiple ways to meet the preferences of different users. As denoted as H1 in Figure 6, the Revenue Growth KPI can be presented as a line graph for trend analysis or as a dial gauge for value comparison.

The BSC can be integrated with the HR database as shown in Figure 7. It provides the contact information of the person responsible for the measure, so that the users can contact the owner of the measure or objective to help address their concerns.

Another important feature of the BSC is Analysis, as illustrated in Figure 7, which provides more detailed information about the plan value, actual value, score, and trend of all the strategies, objectives, and measures. This information helps guide the organization to achieve its organizational goals.

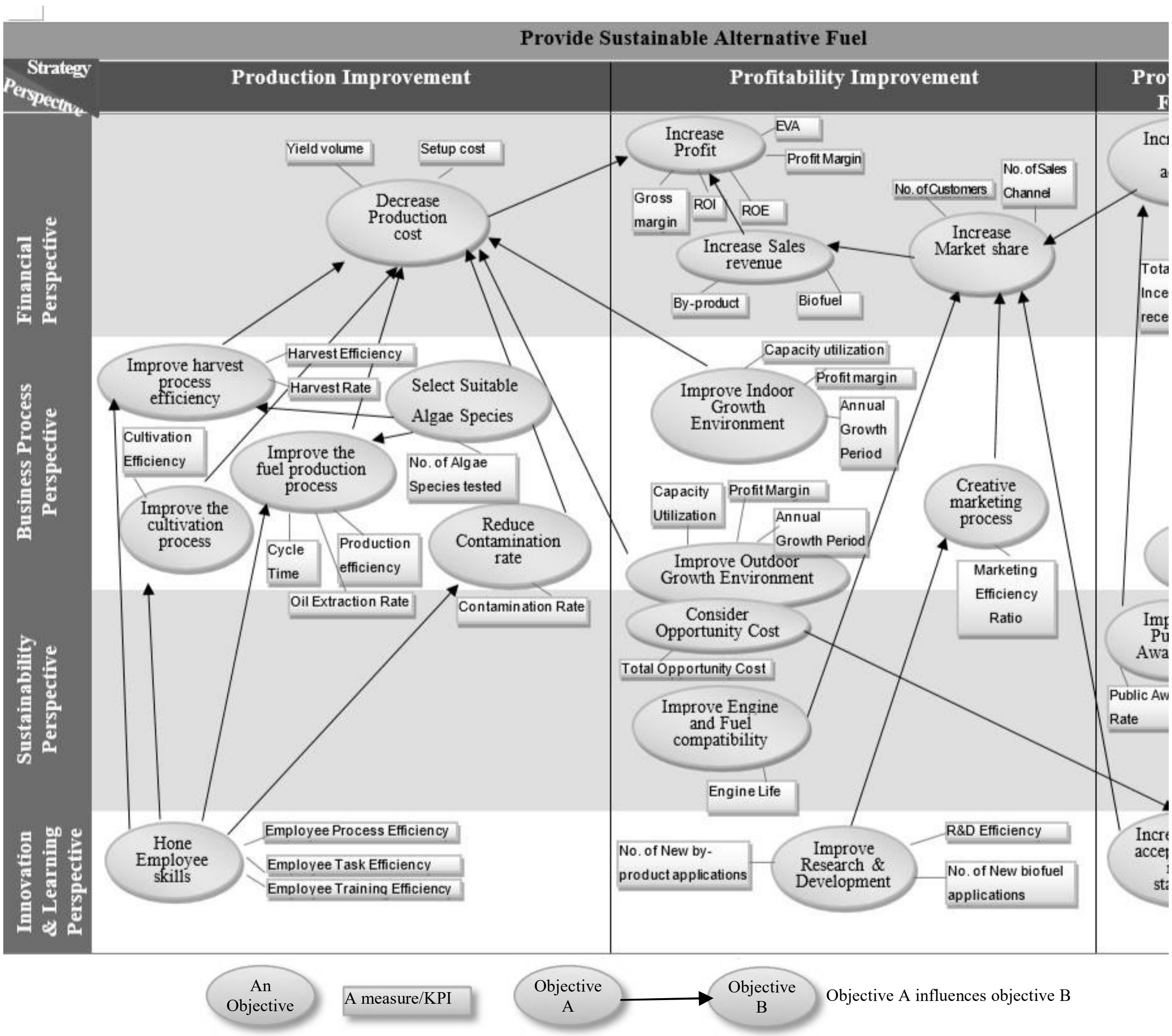

Figure 5. Partial Balanced Scorecard Strategy Map

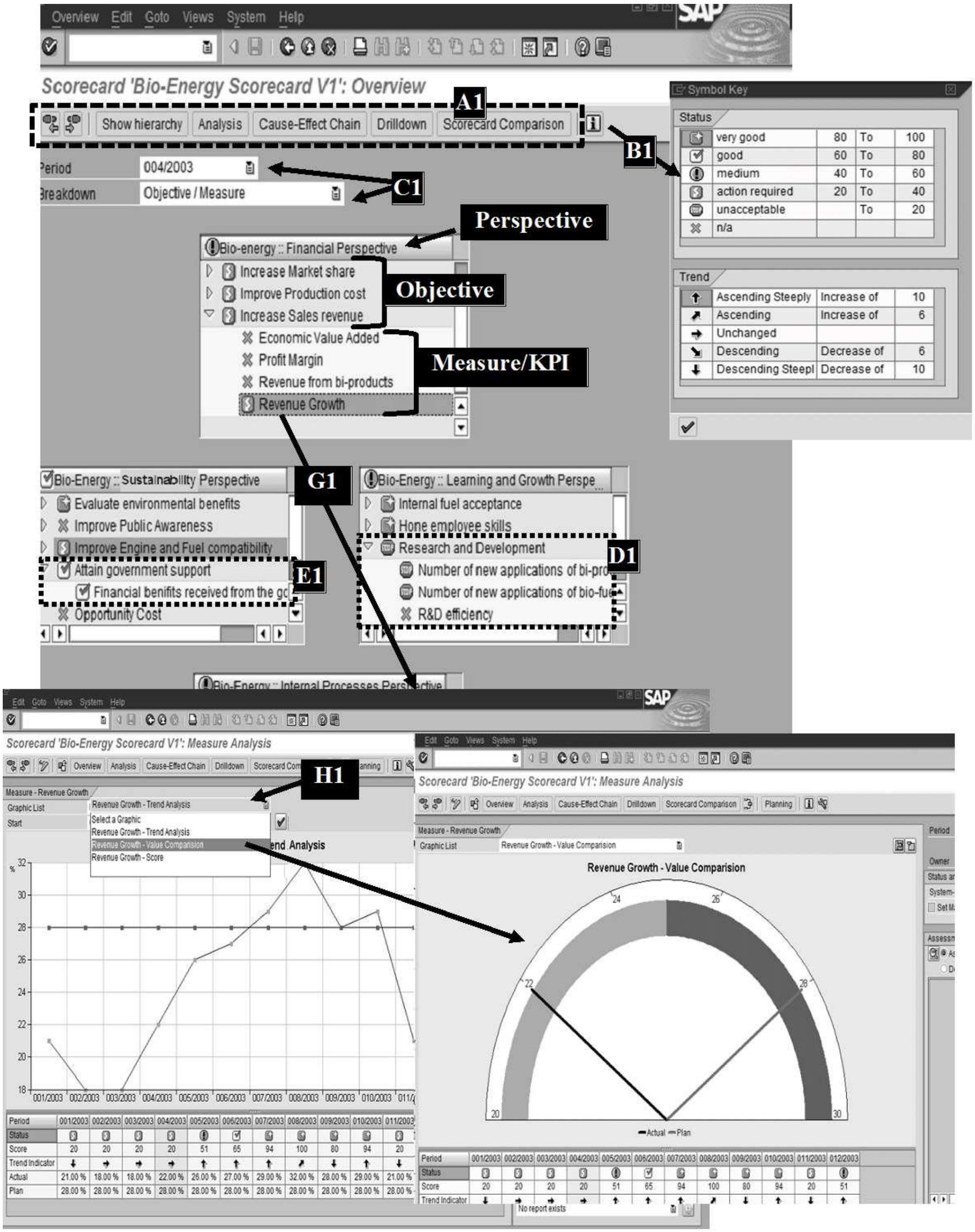

Figure 6. Scorecard Overview and Detailed Drill-Down Ad-Hoc Analysis

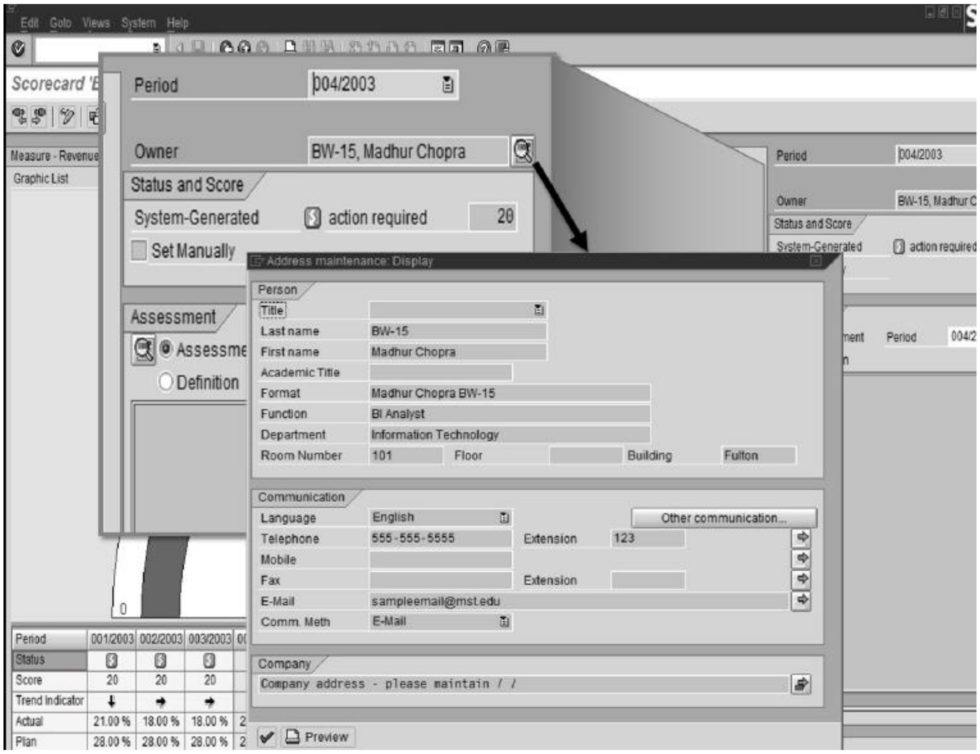

Figure 7. HR Database Integration

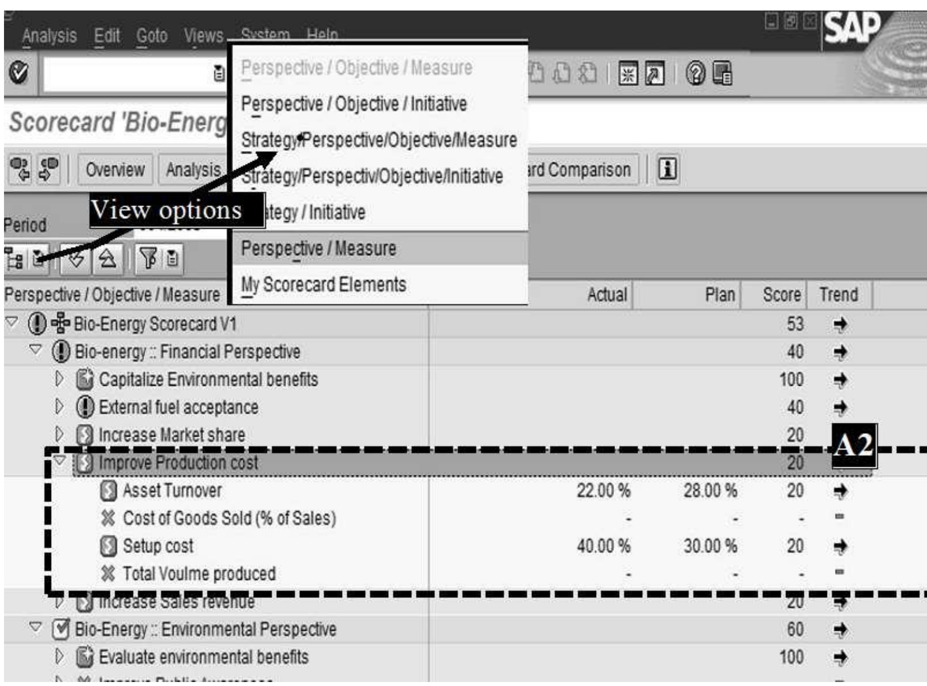

Figure 8. Detailed Drill-Down Ad-Hoc Analysis

CONCLUSIONS

The cost and volume of microalgae based bio-fuel really matter, since they can dictate the bio-fuel commercialization success. Such success often hinges on various influential factors such as temperature, light intensity, and algae strain. Since each step of bio-fuel production poses unique challenges, performance monitoring systems are needed. As such, this paper proposed both dashboards and BSC as a way to systematically monitor and evaluate the bio-fuel production process. In addition, the strategy map was developed to visualize the bio-fuel production and commercialization strategy from different perspectives and under varying environmental factors. To verify the usefulness and practicality of the proposed data visualization approaches (i.e., dashboards, BSC, and strategy map), this paper developed their prototypes using the SAP software.

MAIN CONTRIBUTIONS

This paper is one of the first to develop specific performance metrics and data visualization techniques for gauging the commercialization potential of bio-fuel alternatives based on algae nurturing. In contrast with the traditional performance evaluation, the proposed metrics based on both dashboards and BSC shed lights on four different perspectives (i.e., financial, internal process, innovation, and sustainability) of bio-fuel creation. To elaborate, we attempted to translate intangible environmental benefits (e.g., low air pollution) of alternative fuel into tangible financial figures numbers to assess the financial implications (affordability) of bio-fuel creation. In particular, graphical displays (via the strategy map) of the proposed data visualization techniques allow the decision maker (top management) with limited technical knowledge to fully understand the managerial implications of bio-fuel production and thus help him/her make a wise strategic decision regarding bio-fuel commercialization. Also, it should be noted that the proposed data visualization techniques can be exploited to assess the commercialization potentials of other alternative fuels such as thermal and wind powered energy with minor modifications.

FUTURE RESEARCH DIRECTIONS

Although this research is the point of departure for exploring the commercialization potentials of various alternative fuels, it is still confined to a particular bio-fuel production process available from today's technology. As the bio-fuel technology continues to evolve and advance, a number of factors that are believed to affect the bio-fuel production efficiency may change, while their impacts may either diminish or increase. For instance, the sub production process such as oil extraction and bio-diesel production may be improved over time with advances in bio technology and thus its impact on cost and/or volume may change and the subsequent KPIs and strategy map should be frequently updated. In addition, comparisons of different alternative fuel commercialization potentials will be another line of research which is worth pursuing.

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