Sustainable Entrepreneurship and Innovations for Transitioning the Small and Medium Size Manufacturing Firms to Green Enterprises

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***Abstract*—** This paper examines the major hindrances in moving the small and medium size manufacturing firms, with revenues ranging from U.S 1 to 100 million dollars, towards sustainability conscious and environmentally responsible corporate culture. Economic cost and benefits of transition to greener enterprise are estimated. Case studies of five manufacturing firms in the state of Missouri in US are conducted. Short and long term approaches to achieve the goals of conservation and waste/pollution reduction are determined in consultation with the company senior management; these are based on evolutionary innovations and economic sustainability. The companies are revisited after one year and two years to assess the implementation and its outcome. The successes and failures are noted and are used to generate new ideas and approaches. Some of the lessons learned can be used to improve the entrepreneurial approaches as the manufacturing firm transitions towards environmentally responsible sustainable enterprise.

***Keywords*—**environmentally sustainable manufacturing, evolutionary innovation**,** transition to green enterprise

I. INTRODUCTION

IN recent years, there has been increased emphasis in industry as well as governmental and non-governmental organizations (which include both for-profit and non-profit entities) on sustainability management that combines environmental and social sustainability with economic sustainability [1-5]. Sustainabilty management requires movement from exploitation to exploration, from corporate environmental management to sustainable entrepreneurship, and from efficiency to innovation. Current sustainability trends indicate the need for both revolutionary and evolutionary innovation, which may be brought about by entrepreneurial start-ups as well as new ventures within existing companies. Financing these innovations often are the key bottleneck for sustainable development because research in finance only recently has begun to include the threats and opportunities of sustainability in new business models. In addition, understanding of the changing customer preferences around sustainability and translating them into successful marketing strategies is also critical.

The goal of this research is to analyze various entrepreneurial approaches and paths for evolutionary innovation (with a potential for revolutionary innovation) by using the data from case studies conducted for small to medium size manufacturing firms (with revenues ranging from US 1 to 100 million dollars) in the State of Missouri in USA which are attempting to transition to green enterprises. Case studies data are available for five firms which are part of Missouri Enterprise's Green supplier Network (GSN). These studies were funded by the US Environmental Protection Agency (EPA) and the National Institute of Standards and Technology (NIST).

The Green Supplier Network (GSN) is a consortium of about twenty small and mid-size manufacturers in Missouri that has been organized by Missouri Enterprise for the purpose of helping them meet the EPA 2011 goals of sustainability, which are of substantially reducing the hazardous waste, reducing the energy and water consumption, and curtailing the pollution compared to 2000 baseline levels. Some of the companies in GSN are: Modine, Unilever, Duke Manufacturing, Production Castings, Centrifugal and Mechanical Industries, South Salibury GE, Lee's Summit GE, Slater Filter GE, Independent Stave Company, New Florence Wood Products, Slater Technical GE, Ceramo Inc., Meramec Electrical Products etc. (the list is not complete).

The GSN program focuses on reducing environmental impacts; designing market-based programs; accessing small and medium-sized manufacturers that typically have little interaction with the EPA; and developing and designing environmental activities that point an industry sector toward pollution prevention partly by serving as a delivery system for EPA resources. The program enables small manufacturers to better understand areas of waste, areas of environmental concern and improvement. The goal of the GSN project is to (1) develop state and Manufacturing Extension Partnership (MEP) centers as local GSN champions of the program and (2) develop a self sustaining model for each MEP center to deploy the program. This project further strives to strengthen the local and state relationships between the MEP Centers and state and local environmental agencies and organizations including academic institutions. Additionally, the direct objective of this effort is to inform and improve an organization's

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environmental impacts and help it in achieving the EPA 2011 cumulative goals. 2011 EPA Goals are as follows:

• By 2011, reduce 4.5 billion pounds of hazardous materials cumulatively compared to the 2000 baseline of 44 million pounds reduced.
• By 2011, reduce, conserve, or offset 31.5 trillion British Thermal Units (BTUs) cumulatively compared to the 2002 baseline of 0 BTUs reduced, conserved, or offset.
• By 2011, reduce water use by 19.0 billion gallons cumulatively compared to the 2000 baseline of 220 million gallons reduced.
• By 2011, save $791.9 million through pollution prevention improvements in business, institutional, and governmental costs cumulatively compared to the 2002 baseline of $0.0 saved.

The five companies in GSN (not identified based on their request) have been visited and reviewed by on-site visits. A green review process was developed which showed the companies how they can:

- Improve the use and selection of raw materials
- Reduce labor and capital costs
- Establish systems to use energy more efficiently
- Institute consistent work practices and procedures
- Encourage greater employee participation in improvement activities
- Decrease the use of toxic and/or nonrenewable materials
- Identify potential environmental alternatives
- Identify customer specification conflicts

The Green Suppliers Network reviews followed some of the established MEP Lean & Clean methodologies, which concentrate on the root causes of waste and provide a framework for the successful implementation of Lean & Clean techniques. Cost effective innovative approaches were determined and suggested for implementation. A MEP lean and clean consultant was assigned to each Green Suppliers Network review to work closely with the supplier's management team throughout the process. This data has been utilized in the development of a structural business model for environmentally and economically sustainable enterprises. The following data was collected for each of the five companies:

1. A top-level assessment of the company was performed: the company profile, products, number of employees, annual sales, new product development, expenditures on materials and other supplies, current metric on energy consumption, water consumption, material consumption, and other toxic and non-toxic supplies; expenditures on hazardous waste management and disposal and other environmental pollution (emissions etc.) activity (if any).

2. A complete value stream (process flow) map of one product or process line was developed that included non-value added activities and wastes that could be reduced or eliminated, some of which could require cost-effective innovative solutions.

3. The opportunities for improvement were identified and prioritized to achieve both environmental sustainability goals (for the size of the company) and economic sustainability. The environmental metric included:

a. Energy Conservation (MMBTUs)
b. Water Conservation (Gallons)
c. Air Emission Reduction CO_2 (lbs)
d. Solid Waste Reduction (lbs)
e. Hazardous Waste Reduction (lbs)
f. Toxic / Hazardous Chemical Use Reduction
g. Water Pollution Reduction

It should be noted that the metric for reduction in energy and water usage, hazardous waste reduction etc. varies for companies from one industrial sector to another. We first considered companies in general manufacturing sector that form the GSN. In future, we want to target companies in biotechnology sector, since this sector is growing in Missouri.

The companies in GSN agreed to supply all the necessary data and assign their key employees to work with the Missouri Enterprise representative, the EPA representative (who conducted the environmental assessment) and the author to determine innovative solutions and entrepreneurial approaches for both environmental sustainability and economic performance. The collected data, although limited due to smaller number of participants at this stage of the study, has been the key for developing a realistic process and business model for small and medium size manufacturing firms as they try to transition to greener enterprise. The proposed process and business model can be refined as more data becomes available by participation of additional companies in the GSN.

The model evaluates the environmental sustainability of the manufacturing firm by examining the following goal oriented metric: energy conservation (MMBTUs), water conservation (gallons), CO_2 emission reduction (lbs), solid waste reduction (lbs), hazardous waste reduction (lbs), toxic/hazardous chemical use reduction, and water pollution reduction. The achievement of these goals is assigned a low, medium or high probability based on inputs on management commitment, investment strategy to implement needed evoutionary innovation and the likelihood of achieving product improvement taking into account the market acceptance and the cost. Economic sustainability of the "greener enterprise" is related to the environmental sustainability metric to determine the cost savings to the company by reducing energy consumption, water usage and waste production for the same amount of production; the economic model takes into account the estimated cost of implementating changes based on new technology and practices (termed as evolutionary innovation).

The methodology used in the development of business model is reltaively simple. A set of linear relationships are employed to relate the investments and projected savings over a target time period to achieve the desired environmental sustaianability goals in reducing energy consumption, water usage and hazaradous and non-hazardous waste reduction. The data from five companies in GSN is used for this purpose. The model predicts not only the net financial savings to the

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company, but also the positive effect on the envioronment by decrease in electricity usage, natural gas usage, water usage and waste creation.

II. PROFILES OF COMPANIES AND COLLECTED DATA

In this section, a profile of five companies in GSN is briefly described along with the data on energy usage, water usage, and hazardous and non-hazardous waste creation. Extensive data on all these companies is available but is not given here for the sake of brevity. The companies are also not identified by the name because of lack of permission from their management. They are described as company 1 -5 below.

In the State of Missouri, the cost of electricity, natural gas, water, hazardous and non-hazardous waste disposal is the same for all five companies because they use the same suppliers for these services; these costs vary from one state to the other in US. In Missouri, these costs are 0.07cents/kWh for electricity, 0.85cents/therm for natural gas, 0.01cents/gallon for water, 32.4cents/gallon for hazardous waste removal, and 30.6cents/cubic yards for non-hazardous waste removal. The use of electricity is primarily for manufacturing, lighting and climate control. The use of natural gas is primarily for climate control and manufacturing. The use of water is primarily for manufacturing and climate control. The extensive details of these usage are not given below, again for the sake of brevity.

For each company, the usage of energy, water as well as waste creation is thoroughly examined for each production process as well as in non-production related operations of the company. After this thorough analysis, recommendations are made to the management ranging from investment in new equipment, in streamlining of production processes (by removing redundancy and combining assembly steps through innovative practices etc.), in worker's training and in providing incentives to the workers. The suggestions are also made for improving the non-production processes and the mangement practices.

It is assumed that the level of production and the material used in the production reamains constant. Under these assumptions, the management is presented the cost/benefit analysis of implementation towards a "greener enterprise." In section III, the economic (in terms of incresaed profitabilty) and environmental benefits (in terms of CO_2 and water pollution reduction) expereinced by these five companies are presented.

A. Company 1

Company 1 is a small screen printing company with annual revenue of 1.7 million dollars. Company 1's current pollution prevention and recycling (environmental) activities include:

1. Reuse of cardboard boxes from receiving to shipping
2. Use of misprinted shirts for setups and for rags. These rags are laundered onsite for reuse
3. Recycling of pallets offsite
4. Recycling of paper onsite and offsite. Utilization of waste computer paper in screen printing process
5. Reuse of scrap material from sewing operations
6. Use of crystal-clean wash basin for cleaning equipment
7. Utilization of a "touch-up" process to correct minor mistakes and thus reduce wasted time and material
8. Reuse screens (with graphics) for a common product; this reduces wastage of cleaning and development chemicals
9. Utilize high pressure washing for screen cleaning
10. Minimization of chemical use by using hand application techniques for cleaning; employees do not use bulk chemical application techniques (i.e. sprayers, hoses, etc.)
11. Utilize cloth towels in restrooms instead of paper
12. Reuse plastic packaging liners as trash can liners
13. Recycle plastic and aluminum beverage containers, ink cartridges and toner cartridges
14. Reduced solid waste dumpster volumes from 6 yards to 4 yards

TABLE I
PROFILE OF COMPANY 1 (YEARLY DATA)

Profile & Resource Usage	Data
Revenue (Millions of USD)	$1.71
Employees	25
Floor Space	20,000 Sq. ft
Electricity Usage	187420kW
Natural Gas Usage	11,740Therm
Water Usage	73,500 Gallons
Non-Hazardous Waste Production	6,240 Cubic Yards
Hazardous Waste Production	14,700 Gallons

B. Company 2

Company 2 is a manufacturer of wood and metal display fixtures for U.S. retailers. The assessment covered only the wood part of its operation. The company spends $216,356 on electricity, $216,548 on natural gas and $81,000 on solid waste removal annually. It dumps a 40 yard container of scrap pallets in the landfill weekly. The dumping of pallets represents a large part of the total amount of money going to waste disposal; these pallets can be recycled. The company generated a large quantity of scrap wood that would also go into the landfill. It was found on tour of the facility that the company was throwing away half sheets of wood as scrap. These scrap pieces could be reused or recycled, saving the company significant amount of money. The company also generated 7 bags of fifty- gallons each of sawdust daily which were thrown in the trash; this material could be sold as raw materials for products made by other companies or recycled. There were also audible air leaks. Since the facility operates 16-24 hours per day, it was estimated that there could be savings of $6,235 to $24,922 per year feasible depending on the number and size of the air leaks. It was also observed that the lights were on constantly. Installation of occupancy sensors could reduce the electricity wastage.

All these problems were identified in great detail and recommendations were made to the management for improvement in processes and for investments in equipment and worker's training. These recommendations were implemented resulting in making the company more environmentally responsible and greener but also more profitable as described in section III.

TABLE II
PROFILE OF COMPANY 2 (YEARLY DATA)

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Profile & Resource Usage	Data
Revenue (Millions of USD)	48.41
Employees	278
Floor Space	1,181,000 Sq. ft
Electricity Usage	2,923,800kW
Natural Gas Usage	244,980Therm
Water Usage	73,500Gallons
Non-Hazardous Waste Production	1983 Cubic yards
Hazardous Waste Production	12,600 Gallons

C. Company 3

Company 3 specializes in instant redemption coupons, folded booklets, FDA approved inserts, games and sweepstakes coupons. During tour of the company facility, it was noted that there were audible air leaks. It was further noted that the primary waste stream was the left over matrix material used in the label making process; this material contained paper, plastic and adhesives. It would be difficult to recycle this material; therefore reduction of over runs and more careful planning of material usage could save large quantities of wasted material from going to a landfill. The basic profile of the company and the usage of electricity, natural gas and water, and hazardous and non-hazardous waste production are given in Table III.

Several process improvement opportunities were identified. These opportunities included the upgrade of shadow boards to reduce time wasted in looking for necessary tools and parts. A 5S program was recommended that would result in a cleaner environment. Staging of production material was recommended to increase machine capacity and reduce lead time. A formal maintenance program and routine maintenance program were recommended to ensure that no disruption in production occurs. These recommendations can be considered as evolutionary innovations.

TABLE III
PROFILE OF COMPANY 3 (YEARLY DATA)

Profile & Resource Usage	Data
Revenue (Millions of USD)	1.1
Number of Employees	18
Floor Space	18,000 Sq. ft
Electricity Usage	499,300kW
Natural Gas Usage	11290Therm
Water Usage	58,200 Gallons
Non-Hazardous Waste Production	1650 Cubic yards
Hazardous Waste Production	9,860 gallons

D. Company 4

Company 4 manufactures material handling carts, tables, cabinets, shelving and cart corrals. They also refurbish shopping carts. During the plant visit, it was noted that the company could significantly reduce hazardous waste by using different chemicals in some of their processes. Furthermore, considerable amounts of paint were being wasted because of overspray. It was also noted that filtering and recycling some of the chemicals used in cleaning shopping carts could drastically reduce costs. It was estimated by the Missouri Enterprise led team that $50,000/year could be saved by simply filtering and recycling the cleaning bath of the shopping cart wash line utilizing membrane filtration. This investment would cost about $20,000, which could easily be recovered over a 2 year period. Several energy saving opportunities were also identified. Repairs to leaks in the compressed air lines could save from $6000 to $25,000 annually and installing infrared heaters in the powder coat curing oven could save additional $7000 per year. Reductions in natural gas consumption could be realized by reusing excess heat from the dry-off and cure oven and by insulating the heated wash tanks. Furthermore, the combination of higher efficiency fluorescent lighting and natural lighting could further reduce energy consumption and related costs. The company management was enthusiastic in implementing the recommendations to realize the savings as well as decrease the negative environmental footprint. The basic profile of the company and the usage of electricity, natural gas and water, and hazardous and non-hazardous waste production are given in Table IV.

TABLE IV
PROFILE OF COMPANY 4 (YEARLY DATA)

Profile & Resource Usage	Data
Revenue (Millions of USD)	10
Employees	150
Floor Space	300,000 Sq. ft
Electricity Usage	569,500 kW
Natural Gas Usage	592400 Therm
Water Usage	134200 Gallons
Non-Hazardous Waste Production	7680 cubic yards
Hazardous Waste Production	21,115 gallons

E. Company 5

Company 5 is a small manufacturing firm that makes a ground cover product. They have made some progress in waste reduction; they have reduced scrap generated to 2% along with recycling wherever possible. The Missouri Enterprise led team noted that the majority of the waste generated was paper waste. If a recycling program was implemented at an initial cost of $1450 and $35-$50/month for the service, the investment could be recovered in 0.2 years assuming 50% of the waste could be recycled.

TABLE V
PROFILE OF COMPANY 3 (YEARLY DATA)

Profile & Resource Usage	Data
Revenue (Millions of USD)	1.01
Number of Employees	15
Floor Space	20,000 Sq. ft
Electricity Usage	12,3100 kW
Natural Gas Usage	3850 Therm
Water Usage	16,850 gallons
Non-Hazardous Waste Production	2060 Cubic yards
Hazardous Waste Production	2820 gallons

Several energy savings opportunities were also identified. The management was enthusiastic in implementing the suggested

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recommendations; the substantial savings were realized as well the negative environmental footprint was reduced.

III. LESSONS LEARNED FROM COMPANIES IN SECTION II IN IMPLEMENTATION OF EVOLUTIONARY INNOVATION PRACTICES FOR TRANSTION TO GREENER ENTERPRISE

The manufacturing firms described in section II vary in revenues from USD 1 million to USD 50 million. They have several key common features. They develop, manufacture and market consumer products. They have rather limited investment resources for upgrading the equipment, for changing the product manufacturing stream/cycle and for worker's training for new equipment and processes. Sometime there are difficulties in finding the qualified workers because of location, compensation and needed skills. Under these constraints, the management is reluctant in making changes to achieve environmentally desirable goals of reducing air and water pollution and waste reduction. However, once a detailed audit of the consumption of various resources (electricity, natural gas and water) was conducted, the areas for reducing the consumption were identified. In addition, the inefficient manufacturing equipment and processes were identified and methods for reducing both the hazardous and non-hazardous waste were identified. With this collection of data from the detailed audit, the cost/benefit analysis of evolutionary innovation in the company towards greener enterprise was performed and presented to the management. For a medium and big size firm, this audit and report can be ordered by the company management (this is how it is generally done), but a very small company normally does not want to spend money on this activity. Therefore, for all the five companies described in section II, this activity was primarily funded by NIST, EPA and Missouri department of Natural Resources.

It is also important to take note of another commonality among the five companies in section II; they all use the same primary resources in manufacturing – electricity, natural gas and water. They also generate hazardous and non-hazardous waste. Since they are all located in the state of Missouri in US, they pay the same price for energy and water resources as well as for waste disposal. They face the same environmental and financial regulatory regime as governed by both the federal and state laws.

The most important aspect of this study has been the willingness of the management of all five companies to implement the recommendations, based on the detailed audit, for making changes in the processes, equipment and operations of the company.

It has not been possible for the author to obtain the exact data for substantial savings accrued by these companies in past three years since the implementation plan was put in place in 2008. However, based on the oral communication, it is a safe conclusion that the environmentally responsible plan for product development and realization has increased the profitability of these companies. There is however data available for reduction in electricity consumption by creating improvements in manufacturing processes, using more efficient lighting and HVAV equipment for climate control. This reduction in electricity consumption has not only added to the profitability but has indirectly helped in reducing the CO2 emissions since most of the electricity in Missouri is generated by the coal fired power plants operated by Ameren. The following Table VI shows the amount of CO_2 reduction achieved by the five companies in 2009 by reducing the electricity consumption.

TABLE VI
REDUCTION IN CO_2 EMISSIONS DUE TO REDUCED ELECTRICITY CONSUMPTION

Company	CO_2 Reduction due to change in lighting tubes and bulbs	Net CO_2 Reduction due to improvements in HVAC, manufacturing and lighting
1	20578 lbs.	77257 lbs.
2	1234672 lbs.	1702350 lbs.
3	15043 lbs.	150043 lbs.
4	308765 lbs.	1658765 lbs.
5	99322 lbs.	485036 lbs.

Thus, this study shows that the existing small and medium size manufacturing firms can be made eco-friendly without affecting their profitability (in fact they can increase profits) by implementation of incremental improvements in their production and operational processes (that is by implementing evolutionary innovation). The successful implementation of course requires visionary entrepreneurial mindset. The path towards revolutionary innovation is not clear, especially in the more established traditional manufacturing sector. Most of the revolutionary innovation in last several decades has taken place in information technology and biotechnology industry.

IV. BUSINESS MODEL FOR ECO-ENTREPRENEURSHIP

A process oriented business model for eco-entrepreneurship based on evolutionary innovation is developed using the case studies for five companies described in sections II and III. The model is briefly described here; for details the reader is referred to Reference [6].

The model is based on the assumption that there is a relationship between the total revenue, the possible investment in certain processes/systems (e.g. manufacturing, lighting, HVAC etc.) of the company for both environmental and economic benefit and the resulting potential savings. There are parameters used in the model to quantify savings due to reduction of energy and water usage and waste. The parameters are defined as follows:

$$\beta_{s,n} = \frac{S_{s,n}}{I_{s,n}/\tau}$$

where S is the realized savings due to investments in reducing consumption of s for various processes/systems n , I is the total investment and τ is the recovery time for the investment. The subscript s, denotes the energy or water source; s=1 (electricity), s=2 (natural gas), and s=3 (water). The subscript n denotes the usage area for source; n=1 (manufacturing), n=2 (lighting) and n=3 (HVAC). $\beta_{s,n}$ can be a tabulated value or

can take a functional form if more data becomes available from additional companies.

As shown in Tables I – V, waste reduction can play a large role in saving the money as well as in reducing the pollution. Waste reduction is primarily associated with manufacturing. The waste is divided into two categories - hazardous and nonhazardous because of significant differences in the cost of disposal and the environmental footprint. The waste reduction parameters are also tabulated values but they can also take functional form once more data becomes available from additional companies. The waste reduction parameters are given by:

$$\chi_H = \frac{\frac{WR_H}{W_H}}{\sum_{n=1,2,3} I_{1,n}}$$

$$\chi_{NH} = \frac{\frac{WR_{NH}}{W_{NH}}}{\sum_{n=1,2,3} I_{1,n}}$$

where *WR* is the waste reduction and *W* is the waste. The subscript *H* denotes hazardous and the subscript *NH* denotes the nonhazardous waste.

For a given investment $I_{s,n}$ into source *s* and area *n*, the realized savings can be expressed as:

$$S = \sum_{s=1,2,3}\sum_{n=1,2,3} S_{s,n} + WC_H \cdot W_H \cdot \chi_H \cdot \sum_{n=1,2,3} I_{1,n} + WC_{NH} \cdot W_{NH} \cdot \chi_{NH} \cdot \sum_{n=1,2,3} I_{1,n}$$

where WC_H denotes the cost of hazardous waste removal and WC_{NH} denotes the cost of non-hazardous waste removal.

The total reduction in water usage is given by:

$$H_2O\ reduction = \sum_{n=1,2,3} \frac{S_{3,n}}{P_{water}}$$

where P_{water} is the price of water. The total CO_2 emissions reduction is given by:

$$CO_2\ reduction = \frac{\gamma \sum_{n=1,2,3} S_{1,n}}{P_1} + \frac{\zeta \sum_{n=1,2,3} S_{2,n}}{P_2}$$

where P_1 is the price of electricity, P_2 is the price of natural gas, γ is a conversion factor for electricity generation that relates electricity production to CO_2 emissions and ζ is a conversion factor for natural gas that relates the amount of natural gas burned to CO_2 generated.

This model was applied to the five companies of section II. The realized savings due to investments were calculated. The results were reported to the companies. The calculations from the model were fairly close to the actual realized savings. The environmental impact in terms of CO_2 emission reduction (given in Table VI) was also calculated along with the reduction in nonhazardous and hazardous waste. Based on these validations, it has been concluded that such a simple model can be used to determine a priori the potential savings and positive environmental impact of implementation of some green innovative practices in a company. This model can be refined when more data becomes available with the participation of additional companies. The implementation of innovative strategies of course requires the support of the management, or a supportive entrepreneurial culture.

V. Conclusions

This paper describes the results of case studies of five manufacturing firms in the state of Missouri in US as they try to transition to more eco-friendly enterprises by employing evolutionary innovation to conservation of resources such as energy and water, and reduction of hazardous and non-hazardous waste. It is found that a detailed study of the existing shortcomings in production processes and operations along with the cost/benefit analysis of the implementation of innovative approaches to address the weaknesses can have the management buy-in for making investments and changes that can lead to substantial savings (increased profitability) as well as less adverse impact on environment. Some of the lessons learned can be used to improve the entrepreneurial approaches as the manufacturing firm transitions towards environmentally responsible sustainable enterprise. An eco-friendly business model is also developed that can be used to analyze the economic impact a priori as a company transitions to become a more greener enterprise.

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