DLSU Business & Economics Review 23.2 (2014), pp. 115-131

Developing a Framework for Sustainable Manufacturing Strategies Selection

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Manufacturing organizations adopt sustainability manufacturing in their attempt to address the triple-bottomline (TBL): environmental stewardship, economic growth, and social well-being. This study was conducted in order to characterize the programs adopted by a manufacturing firm with respect to the TBL and in the end, recommend a framework that could be utilized by decision-makers in the firm as they start to pursue a more sustainable strategy. This paper utilized the case study of a prime multinational semiconductor firm that promotes sustainability among their corporate initiatives.The semiconductor industry was chosen because of its prominence in sustainability efforts worldwide. Weaknesses of the current practices were found to be the reactive position of the firm to external drivers due to lack of long-term agenda for sustainability, the lack of reinforcement of social strategies on each other, the fragmented positions of current sustainability strategies along the sustainability "sphere", and the lack of understanding regarding the embedded interrelationships and interdependencies of sustainable manufacturing strategies. A framework is proposed,which captures the influence of internal and external drivers in adopting sustainable manufacturing strategies to address the triple-bottom line. The framework also depicts the influence that external drivers bear on internal ones. This framework could guide decision-makers on sustainable manufacturing strategies selection considering a more holistic approach.

JEL Classification: M19

Keywords: sustainable manufacturing, sustainability drivers, triple-bottom line

Most discussions pertaining to sustainability commence from the report of the United Nations' World Commission on Environment and Development (WCED) popularly known as the Brundtland Commission in 1987. Sustainable development pertains to "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987, p.16). A review on how the area of sustainable development became famous is discussed by Linnenluecke and Griffiths (2010) and its major milestones are detailed by Waas, Huge, Verbruggen, and Wright (2011). Manufacturing industry is regarded as a key sector to sustainable development (Feng & Joung, 2009; Rosen &Kishawy, 2012; Joung, Carrell, Sarkar, & Feng, 2013) because of relatively high amount of materials, energy, and wastes which are required or generated from manufactured products and manufacturing processes. One-third of world energy consumption and CO_2 emissions is accounted for from the manufacturing sector (Nezhad, 2009). Energy demand of the sector would approximately double its figure as projections from 2005-2050 show (Nezhad, 2009; Mani, Madan, Lee, Lyons, & Gupta, 2012). In this regard, an approach termed as sustainable manufacturing has emerged and it is defined based on the definition of the U.S. Department of Commerce as "the creation of manufactured products that use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities and consumers and are economically sound" (Department of Commerce [DOC], 2008; Joung et al., 2013, p.150) which supports the general view of sustainable development. Sustainable manufacturing gains several interests both in industry and academia for a couple of decades and inspires leading developed economies such as the U.S. and U.K. to focus research directions on it (Kovac, 2012). Currently, sustainable manufacturing demands development of products and processes that could address environmental stewardship, economic growth, and social well-being simultaneously. This approach is widely termed as the triple-bottom line approach (Elkington, 1997).

While implementing sustainable manufacturing strategies in a manufacturing organization is undoubtedly beneficial (Azapagic, 2003), there is an increasing discussion regarding how a manufacturing firm is motivated to adopt sustainable manufacturing. Some drivers have directed or motivated manufacturing organizations to embrace sustainable manufacturing philosophy and make sustainable manufacturing as part of their product and process design as well as part of their organizational decision-making process. These drivers are classified into external drivers on which the manufacturing organization has little or no control and internal drivers on which manufacturing organization has full control (Ageron, Gunasekaran,&Spalanzani, 2012; Schrettle, Hinz, Scherrer-Rathje, & Friedli, 2011; Law & Gunasekaran, 2012).

Internal and external drivers direct or influence the selection of sustainable manufacturing strategies. For instance, government policy on minimizing the amount of lead usage in industrial plants such as in semiconductor manufacturing industry could possibly bring conflict to customers and suppliers in the short run and even in the long run. Quality and reliability of semiconductor devices could be adversely affected without the use of lead and the ability of suppliers to develop substitute material for lead could take time as new researches and technologies in material science must be first developed. To meet government's interest, the firm could implement a cleaner production strategy; however, it must be done in context of maintaining quality and reliability of manufactured products. Along with quality requirements of customers, firms must also make sure that cleaner production strategy considers the ability of suppliers to deliver substitute material for lead. This situation however, could only be realized after further research to develop a more appropriate substitute material. The selection of sustainable manufacturing strategies thus must incorporate these external drivers and must view them as decision components in the decision-making process. Along with these drivers, selection of sustainable manufacturing strategies must also take into account the impact of these strategies to the triple-bottom line which is the intersection of the three pillars, that is, environmental, economic, and social dimensions (Joung et al., 2012). Strategies must be formulated to address these dimensions simultaneously; thus providing no enhancement of one dimension at the expense of other dimensions.

Although numerous studies have embarked on theoretically investigating different strategies on their impact to the triple-bottom line (Tseng, Chiu, Lin, & Chinag, 2006; Chien & Shih, 2007;

Franchini, Galeazzo, Furlan, &Vinelli, 2010; Miller, Pawloski, & Standridge, 2010; Yang, Lin, Chan, & Sheu, 2010; Torielli, Abrahams, Smillie, & Voigt, 2010; Yang, Hong, & Modi, 2011; Wong, Lai, Shang, Lu, & Leung, 2012; Schoenherr, 2012; Zailani, Jeyaraman, Vengadasan, & Premkuman, 2012; Gimenez, Sierra, & Rodon, 2012), developing a framework integrating drivers and triple-bottom line is still a gap in current literature. This framework is significant as it provides guidelines from both drivers and the triple-bottom line to the manufacturing industry regarding the selection of sustainable manufacturing strategies. This paper presents a case study which shows that the selection of sustainable manufacturing strategies lacks an integrative framework.It outlines the major gaps of current practice in the selection of sustainability strategies; thus needs a framework which addresses internal and external drivers and simultaneously considers the notion of triple-bottom line.

A semiconductor manufacturing and assembly firm is selected in this study due to the high relevance of semiconductor manufacturing industry in sustainable manufacturing which includes (1) the unprecedented growth in utilization of natural resources as inputs to manufacturing and production; (2) large number of new chemicals introduced every year; (3) the continuing efforts of the semiconductor industry in integrating sustainability in advanced process and research and development; and lastly (4) criticality of product design on environmental safety and health (ESH) viewpoint (Schrader, 2008). A framework is then proposed in this study in the selection of sustainable manufacturing strategies incorporating both internal and external drivers and the triple-bottom line.

LITERATURE REVIEW

The Triple-Bottom Line

The most widely-accepted approach to sustainability in general and to sustainable manufacturing in particular is the triple-bottom line approach (Seuring & Muller, 2008; Adams & Frost, 2008; Jain & Kibira, 2010) introduced by Elkington (1997). This approach maintains that sustainable manufacturing is achieved by considering simultaneously the three pillars of sustainability, that is, environmental stewardship, economic growth, and social well-being (Joung et al., 2012). Sustainable manufacturing could be viewed at the intersection of these three pillars. Intersection of any two pillars could represent sets of programs which address specific issues that may not be truly sustainable at all as described by Rosen and Kishawy (2012) in Figure 1.

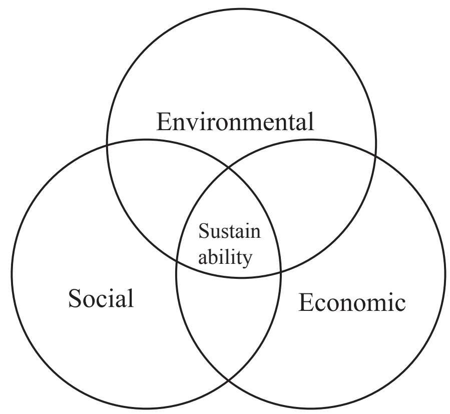


Figure 1. SD as viewed in a Venn diagram (Rosen & Kishawy, 2012).

Empirical studies established some theoretical foundations on approaches that locate in the sustainability region or in regions located at intersections of any two dimensions as portrayed in Figure 4 (Tseng et al., 2006; Chien & Shih, 2007; Franchini et al., 2010; Miller et al., 2010; Yang et al., 2010; Torielli et al., 2010; Yang et al., 2011; Wong et al., 2012; Schoenherr, 2012; Zailani, Jeyaraman, Vengadasan and Premkuman, 2012; Gimenez et al., 2012).

Another stream of research in triple-bottom line is on exploring interdependencies on its three dimensions. The relevance of this area lies in providing information to decision-makers involving investment decisions, resource allocation, strategic planning, and so forth. There are two supporting views in this area. One view suggests that there exists a trade-off in the three dimensions of sustainable manufacturing (Figge & Hahn, 2012; Caniato, Caridi, Crippa, & Moretto, 2012) which implies that improving a single dimension could possibly reduce the performance of other dimension(s). The other view provides guidance on the possible interactions of the three dimensions considering trade-offs. For instance, Yang et al. (2011) and Wagner (2010) maintain that environmental performance has a positive relationship with economic performance. Salzmann, Ionescu-Somers, and Steger (2005) presented a review of the frameworks supporting social and environmental performance to economic performance. Lankoski (2009) also argued that higher revenues (economic sustainability) are achieved with enhanced economic and social performance. Though initial findings in this study are already established, developing integrative holistic models that can treat complex trade-offs in the triple-bottom is still a gap (Gupta & Palsule-Desai, 2011).

The triple-bottom line approach is widely recognized by scholars in the field of sustainable manufacturing (Seuring & Muller, 2008; Jain & Kibira, 2010; Gupta & Kumar, 2013) yet addressing this approach is still a struggle and rare in international setting (Kronenberg & Bergier, 2012). A review of 191 published articles on sustainability suggests that only 31 articles address the triple-bottom line, while 20 articles refer to social dimension and 140 articles refer to greening issues with integrated reference to economic dimension (Ageron et al., 2012). Fragmented analyses exist for economic only (Herron & Braiden, 2006; Lankoski, 2009), green or environmental issues only (Seuring & Muller, 2008), social aspects only (Waage et al., 2005), simultaneously environmental and economic performance (Chien & Shih, 2007; Yang et al., 2011; Giovanni & Vinzi, 2012) or for environmental and social performance (Fiksel, McDaniel, & Mendenhall, 1999). There is a significant motivation in bridging the gap between current fragmented findings and a decision framework incorporating interrelationships of sustainable manufacturing strategies and their impact on the interrelating dimensions of the triple-bottom.

Internal and External Drivers

Compared to traditional cost and quality performance which are tangibles for the firm, the presence of intangibles in sustainable manufacturing such as community well-being, product responsibility, and employee career development makes firms uncertain on whether they would invest in these areas or not. Complexity arises primarily because of the difficulty in quantifying the benefits firms could get out from a particular strategy brought about by longer time horizons and higher degree of uncertainty of the results. Because firms could hardly initiate themselves in moving forward to sustainability, the presence of motivating factors or drivers from different stakeholders plays an important role in pushing manufacturing firms at the frontline of sustainable manufacturing. Examples of external drivers include international standards (Nambiar, 2010), government regulations (Nambiar, 2010; Dornfeld, 2010; Ageron et al., 2012; Schrettle et al., 2011; Deif, 2011), community pressures (Nambiar, 2010; Dornfeld, 2010; Schrettle et al., 2011), customer demands (Dornfeld, 2010; Wu, Tseng, & Vy, 2011; Schrettle et al., 2011; Caniato et al., 2012), shareholder pressures (Nambiar, 2010), competitors, and suppliers' interests (Schrettle et al., 2011). On the other hand, internal drivers include top management pressure (Teixeira, Jabbour, &Jabbour, 2012; Caniato et al., 2012) and organizational culture (Schrettle et al., 2011; Teixeira et al., 2012; Caniato et al., 2012). Notice that external drivers are composed of stakeholders' interests while internal drivers are self-motivated interests by the manufacturing firm. Although top management desire and organizational culture are affected by external pressures to some extent, they are identified separately because firms, which are highly influenced by these, extend their sustainability programs beyond the requirements of external pressures.

There is a growing debate among researchers on which driver influences another driver and which drivers strongly influence manufacturing organizations to adopt sustainable manufacturing strategies. On the first hand, it is viewed by some scholars that regulatory compliance, that is, from government regulations, forms the base why manufacturing organizations adopt sustainable manufacturing (Holton, Glass, & Price, 2010; Ageron et al., 2012). This view extends that internal motivations such as corporate culture and firm's strategy are driven largely by the pressures imposed by the government. Likewise, customer's, supplier's, and competitor's strategies towards sustainability are also motivated by the government. However, Law and Gunasekaran (2012) maintained that a better view of manufacturing firm's motivation to adopt sustainability concepts should be from internal control such as top management support and supportive policies on the development of sustainable manufacturing. This view maintains that the drive of internal management to adopt sustainability is crucial in achieving genuine concern for sustainable manufacturing. Although the latter view seems to be ideal in logical sense, many advocate the former view (Holton et al., 2010; Ageron et al., 2012). This leads to a proposition that external pressures defined by stakeholders composed of primary stakeholders (i.e. customers, shareholders, employees, suppliers and regulators) and secondary stakeholders (i.e. academic institutions, non-government organizations and social activists) (Matos & Silvestre, 2013) dominate and influence internal drivers of manufacturing firms towards sustainability (Ageron et al., 2012; Law & Gunasekaran, 2012). This asserts that internal motivations must be aligned to external ones and not vice versa (Law & Gunasekaran, 2012). This study embarks to this proposition as it supports the view of the transition of manufacturing firm's orientation to sustainability. The latter view, that is, internal drivers as precursors of firm's adoption of sustainability, could be contested by questioning the guidelines on which internal drivers initiate sustainability. It is logically acceptable to think that manufacturing firm's internal management and culture could not be formed out from nothing. It has to obey some guidelines set by external stakeholders. In other words, external drivers serve as prime movers of firm's adoption of sustainability.

Summary of the Literature Review

Selection of sustainable manufacturing strategy involves addressing both internal and external drivers. Since both these drivers have differing degree of influence to the firm, firms thus must develop or select a strategy that would address this without losing focus on the triple-bottom line. Thus, the strategy selection process must consider both drivers and triple-bottom line to provide a holistic approach. Along with this, firms must also understand the complex interrelationships and interdependencies of the drivers and of the dimensions of sustainability. Without this, firms would have fragmented, uncoordinated programs either on implementing strategies which have little bearing to the overall sustainability or focusing only on a single driver or aspect of sustainability. This paper attempts to validate through a case study that at current practice, firms have fragmented sustainability strategies that would not address holistically the internal and external drivers and the triple-bottom line. Gaps would be identified and a conceptual framework is then proposed integrating the drivers and the triple-bottom line in the strategy selection decision-making.

CASE STUDY: FC SEMICONDUCTOR

FC Semiconductor, established for more than 50 years, is a multinational firm and is one of the prime players in the industry. Its foundation could be traced back to the famous Silicon Valley days. Its business processes such as sales, research and development, design, customer and supplier relations, administration, and manufacturing are strategically located in the United States, Europe, Asia, and North America. All of its sites are interdependent of each other in terms of knowledge sharing, human resource, and corporate performance innovation strategies. Each site has its own core business function such as human resource management, research and redevelopment, supply chain management, accounting, and finance. Each of them reports to the headquarters located in the United States. It is a corporation that embraces sustainability as a corporate directive. This case analysis presents the sustainability efforts of the company in its test and assembly manufacturing site in the Philippines. Although it seems to be country specific, however, the strategies developed and implemented in its Philippine site are similar to, if not actually the same as the strategies implemented in other sites. Thus, the results of this analysis would not be country-specific but company-specific in an international setting.

Supportive Strategies forSustainability Programs Implementation

Large firms are likely to embrace sustainability compared to small and medium enterprises because these firms can provide financial investments required for development and implementation of sustainability strategies (Ageron et al., 2012; Law & Gunasekaran, 2012; Hassini, Surti, & Searcy, 2012; Caniato et al., 2012). FC Semiconductor, being a multinational firm, has an advantage of implementing sustainable manufacturing strategies. Same with other corporate strategies, implementation of sustainable manufacturing strategies must be supported internally. This section provides supportive strategies of FC Semiconductor on its implementation of sustainable manufacturing strategies.

- **Top management support**: FC sustainable manufacturing strategies have support from top management. Sustainability, for FC, is a corporate directive,thus, it is embeddedin corporate policies, product design, distribution, marketing, production, and other relevant business processes.
- **Willingness to adopt change**: FC Semiconductor views change as inevitable. Intending to be proactive, the company indulged in a lot of research on new, relevant approaches to cleaner production technologies. Although cleaner production involves relatively higher amount of investment and might inadvertently induce related quality and reliability problems later, the firm pushes harder towards implementation of such ventures. Top management declares its support and commitment to the programs' establishment, implementation, and maintenance.
- **Building relationships within the supply chain**: Collaboration in the supply chain has a positive relationship with quality performance, delivery performance, flexibility performance, and environmental performance (Vachon & Klassen, 2008). FC Semiconductor involves its suppliers in developing cleaner production technologies. The success of FC sustainability programs could also be attributed to the close coordination in the supply chain, particularly, in upstream suppliers. As a result, a green chain effect is proliferated in the supply chain. FC suppliers were forced to develop green products as required by FC and their suppliers' suppliers also were forced to do the same. In other words, developing a chain effect, especially on cleaner production, enhances a sustainable supply chain (Ciliberti, Pontrandolfo, & Scozzi, 2008) which is supplemental in achieving a sustainable manufacturing.

There have also been challenges being faced by downstream customers.

Many customers, at that time of implementation, were not involved in sustainable development programs and many were afraid of the quality and reliability implications of the cleaner production strategy. It tooka lot of discussion and presentation of evaluation and qualification results of the experiments performed by the team. In fact, many customers refused to accept the new substitute and preferred to maintain their previous requirement. When several environmental regulations werealready posted and circulated, these customers conceded and eventually accepted the cleaner production substitutes. Sustainable manufacturing strategies could be hardly developed and implemented without the participation and involvement of downstream and upstream partners in the supply chain (Ageron et al., 2012).

- **Lean Manufacturing Implementation**: Lean manufacturing is widely accepted as a medium to enhance organizations' business performance, particularly market and financial performance (Yang et al., 2011). There is a growing literature claiming that lean manufacturing is positively associated with green manufacturing and environmental performance (Yang et al., 2011; Bergmiller & McCright; 2009;Miller et al., 2010). Having an established lean culture, FC Semiconductor easily implements sustainable manufacturing strategies especially those dealing with environmental concerns. Strategies on team-based problem solving, waste elimination, and value creation, customer-driven decision-makingand just-in-time philosophy are helpful approaches in implementing environmental sustainability programs. The established lean manufacturing culture in FC Semiconductor enhances not only environmental sustainability but economic sustainability as well.

Based on the experience of FC Semiconductor, these organizational practices and strategies supportedthe adoption of sustainable manufacturing.

Sustainable Manufacturing Strategies Developed and Implemented

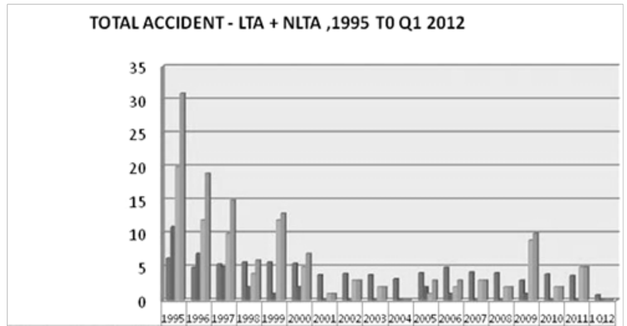
Sustainable manufacturing in FC Semiconductor is characterized by a set of programs which addressed the triple-bottom line. These programs are presented under the dimension on which they exert the most impact. The programs under environmental stewardship and economic growth are discussed in the following sections.

Social well-being.

- **Reforestation Program**: FC Semiconductor launched the "Adopt a Hectare Project" in 2003 which was basically a joint effort with the Philippine Business for Social Progress (PBSP),a professional organization. This project aimedto adopt 16 hectares of land for tree planting. In this project, 40,000 native tree seedlings were planted with reported 66% survival rate in 2009. All employees attended the tree planting activities for a couple of days. Two objectives were in place: (1) regulatory compliance and (2) contribution to local reforestation and rehabilitation of protected areas.
- **Health and Wellness**: As part of enhancing employees' welfare, FC Semiconductor houses canteen, recreational ground, and a clinic inside the plant. The canteen provided employees free food of specified amount during lunch time and snacks. It offereda wide variety of food suitable for a balanced diet. The recreational ground, with a gymnasium, had the complete equipment for body building, exercise, and some sports such as basketball, tennis, and football. The company also regularly organized fun run, sports activities, and

external sports festivals. FC also employed a full-time physician inside the plant. Employees were given 90% discount on all drugs and medications prescribed by the company physician aside from statutory medical benefits. It had a comprehensive package of health benefits to employees and their families as well.

- **Employee Satisfaction**: The firm promoted a learning environment where employees were well-trained locally and internationally with the newest technologies in the semiconductor industry. Managers and senior engineersheld U.S. patents. They were also encouraged to publish their work in scientific journals and to present them in international and local research conferences.
- **Lost Time Injuries**: Another criterion for social sustainability discussed by Fiksel et al. (1999) is lost time injury (LTI). FC Semiconductor promoted this goal on employee safety in the workplace. In its Cebu Plant, as of February 29, 2012, the cumulative man-hours recorded without lost time accident was 9,033,565 reckoned from Sept. 30, 2009. This was way beyond what was recorded by leaders in the industry such as AMCOR (2012), Toyota (2012), and Firmenich (2012). A report from 1995 presented the company's satisfactory record in promoting workplace safety. This is shown in Figure 2. This achievement is a product of FC's effort in establishing, promoting, and maintaining a hazard free production floor. Its continuous effort in promoting occupational safety has been at the forefront of the company's commitment to social sustainability. The effect of this drive is tantamount to building trust, safeguarding family member's welfare at work, and enhancing company's competitiveness in upholding sustainable workplace.



	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	1012
Man-hours Worked in million	6.3	4.9	5.4	5.7	5.7	5.5	3.8	4	3.8	3.2	4.1	4.9	4.2	4.1	3.0	3.9	3.7	0.8
Lost Time accident	11	7	5	2	1	2	0	0	0	0	2	1	0	0	1	0	0	0
Non-lost time accident	20	12	10	4	12	5	1	3	2	0	1	2	3	2	9	2	5	0
Total Accident	31	19	15	6	13	7	1	3	2	0	3	3	3	2	10	2	5	0

Figure 2. Lost time and non-lost time accident report from 1995 to first quarter 2012.

Environmental stewardship.

- **Elimination of Lead (Pb) in Plating Process**: FC Semiconductor implemented cleaner production, otherwise known as "green manufacturing". Green manufacturing is a new paradigm which intends to minimize environmental footprint and serves as a means to cost reduction and improved corporate image (Adams, Thornton, & Sepehri,2011). Directives encourage semiconductor companies with markets particularly in Europe, to be guided by Restriction on the use of certain Hazardous Substances (RoHS) and Waste Electrical and Electronic Equipment (WEEE). Taking it seriously, FC Semiconductor defined its products as "green products", basically compliant to RoHS directives plus a set of more stringent company-set limits.

A significant 85% decrease on the use of lead (in tons per year) was realized by FC from 2007 to 2013. With a decrease in the usage of lead, there was a notable decrease in the lead presentin the bloodstream of employees, particularly thosemost exposed. A 50% reduction was observed from 2007-2010. Laboratory results showed that all parameters, including lead and tin, were below the standard limits set by the National Institute of Occupational Safety and Health (NIOSH), Immediately Dangerous to Life or Health (IDLH), Occupational Safety and Health Association (OSHA), and Philippine Department of Labor and Employment (DOLE). This type of sustainable manufacturing strategy impacts on two aspects of sustainability;that is, environmental stewardship and social well-being dimensions.

- **"Green" Mold Compound**: In the semiconductor encapsulation process, packages go through a transfer molding process which previously used a molding compound containing halogen—the presence of phosphorus, bromine (flame retardant) and antimony. Bromine and antimony are restricted substances by RoHS as these can cause environmental hazard. As a result of extensive research, FC Semiconductor initiated the use of a "green" molding compound.An alternative component of bromine and antimony, (metal hydroxide and multi-aromatic resin) was used, ensuring the absence of halogens in mold compounds.As the process of converting from traditional mold compound to a green mold compound required several quality and reliability tests, FC Semiconductor performedagradual implementation of the change. The entire conversion was accomplished in 2010 since it started in 2007.
- **Phasing-out PVC in Plastic Packaging**: Due to potential adverse effects associated with perfluorinated chemicals and PVC (polymer vinyl chloride), FC Semiconductor bannedits use in manufacturing, storing, and transporting products. The emission of mercury, dioxin, and phthalates during the life cycle of PVCwas a concern. Driven also by customer requirements, FC developed a new material, PETG, which complieswith the RoHS requirements and the quality requirements set by the firm. Started in 2007, the entire conversion to PETG in all FC's products wascompleted in 2010.
- **Energy Efficient Products**: FC Semiconductor is the leading supplier of power semiconductors worldwide. Its products optimize system power therefore helping its customers and its end-users reduce energy consumption and mitigate their environmental impact. Its products are used for efficient computing, automotive, consumer, home appliance, industrial energy conservation, lighting, medical, mobile, network communication, and power supply.

Economic growth.

- **Embedded economic benefit**: Each sustainable manufacturing strategy focusing on social well-being had an embedded economic benefit: primarily for the employees and secondarily for the firm as higher performance was achieved having personnel who have low absenteeism and were highly satisfied with their work. With regards to the reforestation program, the society was bound to benefit economically as it ensures that future generations will find this as available resource for their use. Although it will not be available readily, this venture addressed socio-economic pressures, the effects of which could bring about dire consequences to the society.The programs focusing on environmental stewardship had underlying positive economic effects. The activities that were a result of complying with government regulations could be considered as an investment for the firm as the governments will in the future be more stringent with regards to environmental concerns. This is an expected general trend with regards to the environmental regulations across government bodies. For those FC adopted programs which were more proactive in its desire to anticipate and preempt stricter regulations, the firm just intended to be ahead of its competitors as it could reap the benefits of one-time capital outlay for the improvement of the process over a staggered or phase-by-phase improvement of the process when government regulations required.

- **Lean Methodologies and Six Sigma Quality**: When wastes were eliminated through lean methodologies, processes were expected to deliver higher output at a faster rate and this is tantamount to reducing costs and yielding more profit. However, lean manufacturing did not bring production output to a controlled quality by way of reducing process variation. SixSigma Qualitywas developed to bring products and processes to customer specification at lower rejection rate of around 3.4 ppm. The famous DMAIC (Define-Measure-Analyze-Improve-Control) approach made FC Semiconductor strive for quality excellence. When these two approaches were simultaneously used, then speed and accuracy to the production process were ensured. FC Semiconductor, almost a decade ago, embraced lean manufacturing and half a decade ago, incorporated Six Sigma to its plant. With these two approaches, FC managed toreduce costs and strengthen customer relationships.
- **Energy Management**: FC Semiconductor organized a cross-functional plant-wide team tasked to generate energy conservation ideas, perform energy awareness drive, implement energy conservation projects, do energy audits, and perform monitoring and measurement. In 2010, there were 52 energy management projects designed and implemented by the company, which is equivalent to reduction of energy costs by US$37,600. This was accounted for power cost reduction by 118,557 kWh which is equivalent to US$19,225, water use reduction by 474.5 cu. m. equivalent to US$1,571, forming gas use reduction by 5,493.6 cu. m. equivalent to US$2,093, and nitrogen use reduction by 101,243 cu. m. equivalent to US$14,691. Energy savings or reduction of 118,557 kWh is equivalent to reduction of 82 metric ton of carbon footprint. This energy management program directs two aspects of the triple-bottom line—economic and environmental aspects. This relationship confirms the interdependencies of the triple-bottom line.

PROPOSED FRAMEWORK

Gaps and Issues of Current Practice

Although FC semiconductor implements strategies to address social, environmental, and economic demands, there are relevant gaps thatare significant in providing a holistic approach for long-term sustainability. First, it could be noted that FC semiconductor is not proactive especially in dealing with environmental sustainability strategies. Strategies implemented are highly directed by government regulations and policies. The firm lackedlong-term agenda or strategic plan of programs and activities to address sustainability (Keijzers, 2002). A common experience among manufacturing firms, this lack of long-term strategic plan makes them try some strategies which they consider as novel in the industry without looking at its capability to deliver results addressing the needs of the stakeholders. Decision-makers have to understand which strategy or strategies address the requirements of a particular driver and which address all the drivers. Second, strategies developed to address mainly the social aspect do not seem to link up with other strategies. Thus, these strategies may not reinforce each other and may not bring the firm to a higher level of sustainability, even with a high level of effort placed in one strategy. This could lead manufacturing organizations to take for granted social sustainability as they could not clearly see the value in pursuing such strategies.

Third, strategies are fragmented and scattered along the sustainability sphere. By letting So1 be the first bullet in Social well-being, En1 be the first bullet in Environmental stewardship and Ec1 be the first bullet in Economic growth, Figure 3 shows the location of these strategies in the diagram.

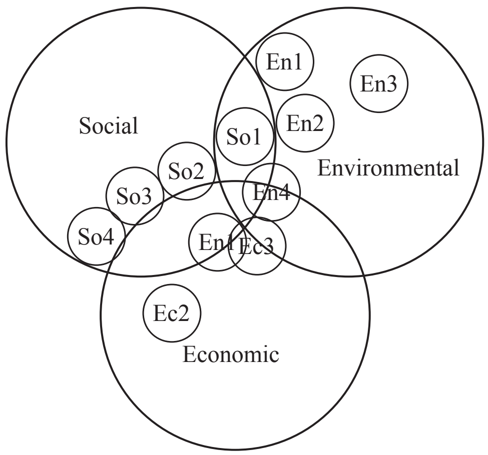


Figure 3. Locations of FC Semiconductor sustainable manufacturing strategies in the sustainability sphere.

In this case study, the drivers of the different strategies were sought and their influence on the formulation of the different strategies were investigated and documented. These are presented in Table 1 in a matrix form which relates the drivers to thesustainability strategies. In the right-hand column is the sustainability dimension/s addressed by each strategy. This was obtained in consultation with the implementing managers of the said programs.

These strategies fall short of the genuine sustainability agenda (Rosen &Kishawy, 2012). Only one strategy is purely on the triple-bottom line and the other two have weak relations to it. Relating drivers to strategies, government-related pressures are addressed mostly by the firm's strategies. This supports the view of Holton et al. (2010) and Ageron et al. (2012), which claims that government regulations form the base of sustainability agenda. The rest of the drivers are not truly addressed by the firm's strategies. An ideal scenario should be that most,

Table 1
Driver-Strategy-Triple-bottom Line Relationship Matrix

Drivers								Strategies	Triple-Bottom Line			
Shareholders	Competitors	Government	Suppliers	Customers	Consumers	Employees	Community		Social Sustain-ability	Environmental Sustainability	Economic Sustainability	All Three Dimensions
		√					√	So1: Reforestation program	√	√		
		√				√		So2: Health and wellness	√		√*	
		√				√		So3: Employee satisfaction	√		√*	
√		√				√		So4: Lost time injuries	√		√*	
		√	√	√	√	√	√	En1: Elimination of Lead (Pb)	√*	√		
		√	√	√	√	√	√	En2: Green mold compound	√*	√		
		√			√		√	En3: Phasing out of PVC		√		
√	√	√	√	√	√			En4: Energy efficient products	√	√	√	√
√			√			√		Ec1: Embedded economic benefit	√	√	√	√*
√	√					√		Ec2: Lean methodologies and six sigma quality			√	
√		√					√	Ec3: Energy management	√*	√	√	√*

*minimal or weak relation

if not all, of the strategies addressed the entire set of drivers. These numbers show that FC's effort is wandering around with less focus on the triple-bottom line target. A framework is thus necessary to move these strategies at the intersection of the three dimensions. Lastly, FC Semiconductor lacks understanding of interdependencies of the sustainable manufacturing strategies. Understanding such complex interrelationships would bring twofold benefits for the firm. First, it could optimize the use of resources and investments for a particular strategy that supports other strategies. This would provide information on which strategy to select in order to increase sustainability level of a manufacturing firm.And secondly, it assists in laying out strategic plans for firms in drawing their roadmap to sustainability. Considering these gaps in literature on current practice of sustainability adoption, there is thus a need to develop a conceptual framework which considers the influence of internal and external drivers and of the triple-bottom line.

Conceptual Framework

Various conceptual models are developed in literature from the factory level (Chen, Heyer, Seliger, & Kjellberg, 2012; Yuan, Zhai, & Dornfeld, 2012), the supply chain (Olugu, Wong, & Shaharoun, 2010; Duflou et al., 2012) and through the product life cycle (Reich-Weiser & Dornfeld, 2008; Dhingra, Naidu, Upreti, & Sawhney, 2010). Recent models for corporate decision-making are also developed in literature. Reich-Weiser, Vijayaraghavan, & Dornfeld (2008) developed a top-down, horizontal, and vertical approach of sustainable manufacturing considering spatial and temporal views. The model is used to determine metrics to be used for design and analysis from goal and scope definition approach. Although the metrics could serve as a guide to strategy selection, they do not provide sufficient capability to handle complex interrelationships of different strategies. The model developed by Svensson, Wood, and Callaghan (2010) is intended for analyzing sustainable business practices from an ethical perspective. This model could not handle the gaps identified in section on gaps and issues of current practice. Azapagic (2003) developed a corporate sustainability management system which illustrated a cycle from sustainable development policy generation, planning, implementation, communication, and review and corrective action. This is an excellent model which would guide the management on handling sustainability projects but it does not describe strategy selection in the context of interrelationships. The model developed by Subic,

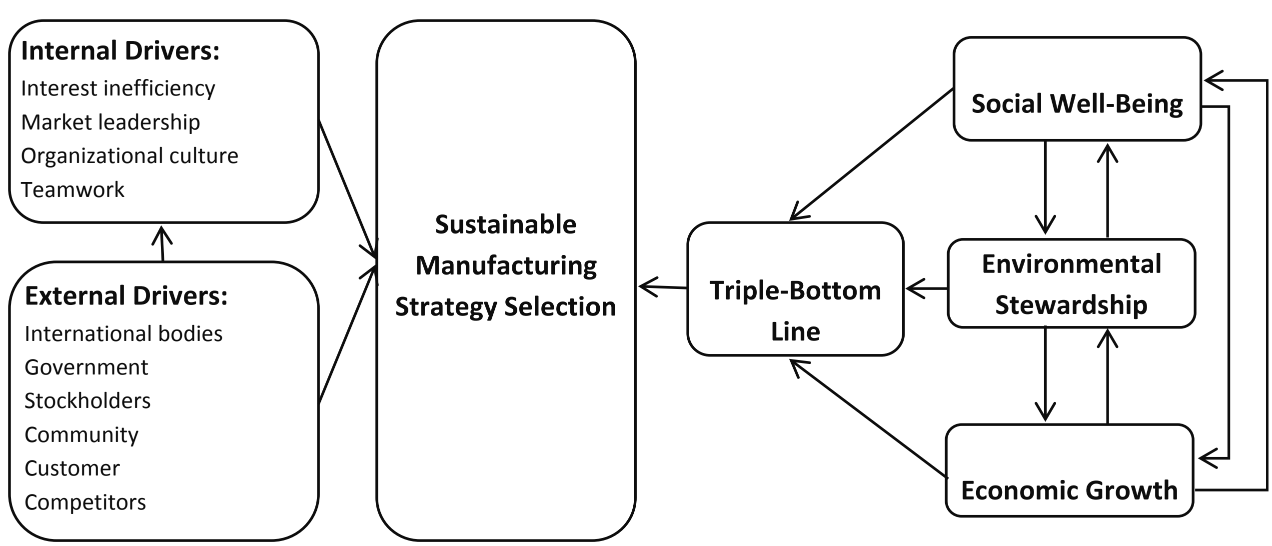


Figure 4. Proposed conceptual framework

Shabani, Hedayati, & Crossin (2012) is only limited to environmental sustainability. Thus, a framework is needed to address the gaps identified in the case study. The proposed framework is shown in Figure 4.

The proposed framework integrates both internal and external drivers and the triple-bottom line. External drivers influence internal drivers as proposed in literature (Holton et al., 2010; Ageron et al., 2012; Law & Gunasekaran, 2012). For instance, customers' requirement of excellent quality in manufactured products encourages manufacturing organizations to maintain their own quality policy and develop a culture of quality excellence. Both internal and external drivers influence the strategy selection but of different levels of influence. Strategy selection must not be influenced by individual sustainability dimensions but must serve the intersection of these dimensions—the triple-bottom line.In the attempt to address the triple-bottom line, manufacturing organizations must understand the complex interdependencies of the three dimensions. These interdependencies may often involve trade-offs, opposing, and conflicting relationships.

SUMMARY AND FUTURE WORK

This study draws a proposition that in current practice, manufacturing firms lack an integrative framework in sustainable manufacturing strategy selection. A case study in FC Semiconductor is done to show that sustainability strategies are fragmented as they lack a clear direction on which sustainability drivers they try to address and if they really hit the triple-bottom line. These two areas are significant in decision-making as they provide information on investment decisions and guide for developing long-term strategic plans for sustainability. Through the case study, it is known that the strategies implemented by the manufacturing firm could be classified in terms of the three dimensions of sustainability. The choice of these strategies depends largely on industry-driven regulations, availability of industry-benchmarked technologies, supportive programs in the locality, and management openness to espouse business or organizational philosophies. These strategies are strengthened with supportive strategies such as top management support, presence of lean manufacturing, coordination, and collaboration in the supply chain.

However, significant issues and gaps in current practice are identified which include the reactive position of the firm to external drivers due to lack of long-term agenda for sustainability, the lack of reinforcement of social strategies to each other, the fragmented positions of current sustainability strategies along the sustainability sphere, and the lack of understanding of embedded interrelationships and interdependencies of sustainable manufacturing strategies.Thus, a conceptual framework is proposed in this study that integrates internal and external drivers and the notion of triple-bottom line. The framework captures the complex interrelationships of sustainable manufacturing strategies together with the idea that external drivers influence internal ones. The proposed framework could guide decision-makers on sustainable manufacturing strategies selection in a holistic approach. Future studies could be extended from this work. First is to test the validity of the model through statistical multivariate methods. This could be done by treating each component as construct and thus could be defined by measurable elements. A confirmatory factor analysis and structural equation modeling could be applied to test model validity. Second is to apply the proposed framework in decision-making. Since decision components are linked through loops, an Analytic Network Process is recommended to evaluate the decision-making. This general framework could be extended to suit the needs of a particular manufacturing industry.

REFERENCES

Adams, C.A., & Frost, G.R. (2008). Integrating sustainability reporting into management practices. *Accounting Forum*, *32*(4), 288-302.

Adams, M., Thornton, B., & Sepehri, M. (2011). The impact of the pursuit of sustainability on the financial performance of the firm. *Journal of Sustainability and Green Business*, *1*, 1-14.

Ageron, B., Gunasekaran, A. & Spalanzani, A. (2012). Sustainable supply management: an empirical study. *International Journal of Production Economics*, *140*(1), 168-182

AMCOR. (2012). Sustainability report 2012. Retrieved from http://media.amcor.com/documents/Amcor-2012-sustainability-report-summary.pdf

Azapagic, A. (2003). Systems approach to corporate sustainability: Ageneral management framework. *Process Safety and Environmental Protection*, *81*(5), 303-316.

Bergmiller, G.G., & McCright, P.R. (2009). Lean manufacturers' transcendence to green manufacturing. In *Proceedings of the 2009 industrial engineering research conference* (pp. 99-113). Miami, Florida.

Brundtland, G. H. (1987). Report of the world commission on environment and development: Our common future. Oxford, UK: Oxford University Press.

Caniato, F., Caridi, M., Crippa, L., & Moretto, A. (2012). Environmental sustainability in fashion supply chain: An exploratory case based research. *International Journal of Production Economics*, *135*(2), 659-670.

Chen, D., Heyer, S., Seliger, G., & Kjellberg, T. (2012). Integrating sustainability within the factory planning process. *CIRP Annals-Manufacturing Technology*, *61*(1), 463-466.

Chien, M.K., & Shih, L.H. (2007). An empirical study of the implementation of green supply chain management practices in the electrical and electronic industry and their relation to organizational performances. *International Journal of Environmental Science and Technology, 4*(3), 383-394.

Ciliberti, F., Pontrandolfo, P. & Scozzi, B. (2008). Logistics social responsibility: Standard adoption and practices in Italian companies. *International Journal of Production Economics, 113*(1), 88-106.

Deif, A.M. (2011). A system model for green manufacturing. *Journal of Cleaner Production*, *19*(14), 1553-1559.

Department of Commerce (DOC). (2008). How does commerce define sustainable manufacturing? Retrieved from http://trade.gov/competitiveness/sustainablemanufacturing/how_doc_defines_SM.asp

Dhingra, R., Naidu, S., Upreti, G., & Sawhney, R. (2010). Sustainable nanotechnology: Through green methods and life-cycle thinking. *Sustainability*, *2*(10), 3323-3338.

Dornfeld, D. (2010). Sustainable Manufacturing-Greening Processes, Systems and Products. *Green manufacturing and sustainable manufacturing partnership* (pp. 99-113). California: Laboratory for Manufacturing and Sustainability, UC Berkeley.

Duflou, J.R., Sutherland, J.W., Dornfeld, D., Herrmann, C., Jeswiet, J., Kara, Kellens, K. (2012). Towards energy and resource efficient manufacturing: Aprocess and systems approach.*CIRP Annals-Manufacturing Technology*, *61*(2), 587-609.

Elkington, J. (1997). *Cannibals with forks: The triple-bottomline of 21st century business*. Oxford: Capstone.

Feng, S.C., & Joung, C.B. (2009).*An overview of a proposed measurement infrastructure for sustainable manufacturing*.Paper presented at the7th Global Conference on Sustainable Manufacturing,Indian Institute of Technology Madras,December 2-4, 2009.

Figge, F., & Hahn, T. (2012). Is green and profitable sustainable? Assessing the trade-off between economic and environmental aspects. *International Journal of Production Economics*,*140*(1), 92-102.

Fiksel, J., McDaniel, J., & Mendenhall, C. (1999). Measuring process towards sustainability: Principles, process and best practices. In

Proceedings of the 1999 greening of industry network conference.Netherlands: Greening of Industry Network (GIN).

Fimenich. (2012). Firmenicksustainability report 2012.Retrieved from http://www.firmenich.com/SustainabilityReport2012/FIRMENICH-SUSTAINABILITY-REPORT-2012.pdf

Franchini, V., Galeazzo, A., Furlan, A. and Vinelli, A. (2010). Sustainable operations and lean management: Towards an integrated approach. In *Proceedings of POMS 21st annual conference,*Vancouver, Canada.

Giovanni, P.D., & Vinzi, V.E. (2012).Covariance versus component-based estimations of performance in green supply chain management. *International Journal of Production Economics*, *135*(2), 907-916.

Gimenez, C., Sierra, V., & Rodon, J. (2012). Sustainable operations: Their impact on the triple-bottom line. *International Journal of Production Economics*, 140(1), 149-159.

Gupta, S., & Kumar, V. (2013). Sustainability as corporate culture of a brand for superior performance. *Journal of World Business*, *48*(3), 311-320.

Gupta, S., & Palsule-Desai, O.D. (2011). Sustainable supply chain management: Review and research opportunities. *IIMB Management Review*, *23*(4), 234-245.

Hassini, E., Surti, C., & Searcy, C. (2012). A literature review and a case study of sustainable supply chains with a focus on metrics. *International Journal of Production Economics*, *140*(1), 69-82.

Herron, C., & Braiden, P.M. (2006). A methodology for developing sustainable quantifiable productivity improvement in manufacturing companies. *International Journal of Production Economics*, *104*(1), 143-153.

Holton, I., Glass, J., & Price, A.D.F. (2010). Managing for sustainability: Findings from four company case studies in the UK precast concrete industry. *Journal of Cleaner Production*, *18*(2), 152-160.

Jain, S., & Kibira, D. (2010). A framework for multi-resolution modeling of sustainable manufacturing. In B. Johansson, S. Jain, J. Montoya-Torres, J. Hugan, & E. Yücesan(Eds.), *Proceedings of the 2010 winter simulation conference* (pp. 3423-3434). Baltimore, Maryland: DBLP.

Joung, C.B., Carrell, J., Sarkar, P., & Feng, S.C. (2013). Categorization of indicators for sustainable manufacturing. *Ecological Indicators*, *24*, 148-157.

Keijzers, G. (2002). The transition to the sustainable enterprise. *Journal of Cleaner Production*, *10*(4), 349-359.

Kovac, M. (2012). Comparison of foresights in the manufacturing research. *Transfer Inovacii*, *23*, 284-288.

Kronenberg, J., & Bergier, T. (2012). Sustainable development in a transition economy: Business case studies from Poland. *Journal of Cleaner Production*, 26, 18-27.

Lankoski, L. (2009). Cost and revenue impacts of corporate sustainability: Comparisons across sustainability dimensions and product chain stages. *Scandinavian Journal of Management*, 25(1), 57-67.

Law, K.M.Y., & Gunasekaran, A. (2012). Sustainability development in high-tech manufacturing firms in Hongkong: Motivators and readiness. *International Journal of Production Economics*, *137*(1), 116-125.

Linnenluecke, M.K., & Griffiths, A. (2010). Corporate sustainability and organizational culture. *Journal of World Business*, *45*(4), 357-366.

Mani, M., Madan, J., Lee, J.H., Lyons, K., & Gupta, S.K. (2012). Characterizing sustainability for manufacturing performance assessment. In *Proceedings of the ASME 2012 international design engineering technical conferences and computers and information in engineering conference volume 2,* Chicago, Illinois: ASME. doi: 10.1115/DETC2012-70455.

Matos, S., & Silvestre, B.S. (2013). Managing stakeholder relations when developing sustainable business models: The case of the Brazilian energy sector. *Journal of Cleaner Production*, *43*, 61-73.

Miller, G., Pawloski, J., & Standridge, C. (2010). A case study of lean, sustainable manufacturing. *Journal of Industrial Engineering and Management, 3*(1), 11-32.

Nambiar, A.N. (2010). Challenges in sustainable manufacturing. In: *Proceedings of the 2010 international conference on industrial engineering and productions management*. Dhaka, Bangladesh.

Nezhad, H. (2009). *World energy scenarios to 2050: Issues and options*(White Paper). Minnesota: Metropolitan State University Minneapolis.

Olugu, E.U., Wong, K.Y., & Shaharoun, A.M. (2010). A comprehensive approach in assessing the performance of an automobile closed-loop supply chain. *Sustainability*, *2*(4), 871-889.

Reich-Weiser, C., & Dornfeld, D. (2008). *Environmental decision-making: Supply chain considerations*. California: Green Manufacturing and Sustainable Manufacturing Partnership, Laboratory for Manufacturing and Sustainability, UC Berkeley.

Reich-Weiser, C., Vijayaraghavan, A., & Dornfeld, D. (2008). Metrics for sustainable manufacturing. In *Proceedings of the ASME 2008 international manufacturing science and engineering conferencevolume 1,*(pp. 327-335). Evanston, Illinois: ASME.doi:10.1115/MSEC_ICMP2008-72223

Rosen, A., & Kishawy, H. (2012). Sustainable manufacturing and design: Concepts, practices and needs. *Sustainability, 4*(2)*,* 154-174.

Salzmann, O., Ionescu-Somers, A., & Steger, U. (2005). The business case for corporate sustainability: Literature review and research options. *European Management Journal*, *23*(1), 27-36.doi:10.1016/j.emj.2004.12.007

Schoenherr, T. (2012). The role of environmental management in sustainable business development: Amulti-country investigation. *International Journal of Production Economics*,*120*(1), 116-128.

Schrader, G. (2008). *Environmental sustainability in nano-manufacturing for the semiconductor industry*.Paper presented at the NSF/ARC Nanotechnology Innovation and Entrepreneurship in Water, Energy, and Materials, Brisbane, Australia. Retrieved from: http://www.aibn.uq.edu.au/Download/NSF/Glenn_Schrader_UAriz.pdf

Schrettle, S., Hinz, A., Scherrer-Rathje, M., & Friedli, T. (2011). The impact of sustainability drivers on a firm's strategic decisions regarding manufacturing technologies, new product development and supply chain initiatives. In D. Spath, R. Llg, & T.Krause (Eds.), *Proceedings of the ICPR 21st international conference on production research*. Stuttgart, Germany: Fraunhofer-Verlag.

Seuring, S., & Muller, M. (2008).From a literature review to a conceptual framework for sustainable supply chain management. *Journal of Cleaner Production*, *16*(15), 1699-1710.

Subic, A., Shabani, B., Hedayati, M., & Crossin, E. (2012). Capability framework for sustainable manufacturing of sports apparel and footwear. *Sustainability*, *4*(9), 2127-2145,

Svensson, G., Wood, G., & Callaghan, M. (2010). A corporate model of sustainable business practices: An ethical perspective. *Journal of World Business*, *45*(4), 336-345.

Teixeira, A.A., Jabbour, C.J.C., & Jabbour, A.B.L.d.S. (2012). Relationship between green management and environmental training in companies located in Brazil: Atheoretical framework and case studies. *International Journal of Production Economics*, *140*(1), 318-329.

Torielli, R.M., Abrahams, R.A., Smillie, R.W., & Voigt, R.C. (2010). Using lean methodologies for economically and environmentally sustainable foundries.*China Foundry*, *8*(1), 74-88.

Toyota (2012).*Toyota European sustainability report 2012*.Retrieved from https://www.google.com.ph/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&ved=0CC0QFjAB&url=http%3A%2F%2Fwww.toyota.eu%2Fsustainability%2FPages%2FDownloadFile.ashx%3Fpath%3DSustainability%2520Report%2520Documents%2FSustaina

bility%2520Report%25202012%2FToyota_European_Sustainability_Report_2012.pdf&ei=8_bpUcfwGoqriAegsoGwAw&usg=AFQjCNF2WPc5p5C3TiA1HonzIZgFCpNJKQ&sig2=8S_NpCuk1zuQAGG5z-6GBw&bvm=bv.49478099,d.aGc

Tseng, M.L., Chiu, A.S.F., Lin, Y.H., & Chinag, J.H. (2006). The relationship of continuous improvement and cleaner production on operational performance: An empirical study in electronic manufacturing firms, Taiwan China. *International Journal of Management Science and Engineering Management*, *1*(1), 71-80.

Vachon, S., & Klassen, R. (2008). Environmental management and manufacturing performance: The role of collaboration in the supply chain. *International Journal of Production Economics, 111*(2), 299-315.

Waage, S.A., Geiser, K., Irwin, F., Weissman, A.B., Bertolucci, M.D., Fisk, P., … McPherson, A. (2005). Fitting together the building blocks for sustainability: Arevised model for integrating ecological, social and financial factors into business decision-making. *Journal of Cleaner Production*, *13*(12), 1145-1163.

Waas, T., Huge, J., Verbruggen, A.,& Wright, T. (2011). Sustainable development: Abird's eye view.*Sustainability, 3*(10)*,* 1637-1661.

Wagner, M. (2010). The role of corporate sustainability performance for economic performance: A firm-level analysis of moderation effects. *Ecological Economics*, *69*(7), 1553-1560.

Wong, C.W.Y., Lai, K.H., Shang, K.C., Lu, C.S., & Leung, T.K.P. (2012). Green operations and the moderating role of environmental management capability of suppliers on manufacturing firm performance. *International Journal of Production Economics*, *140*(1), 283-294.

Wu, K.J., Tseng, M.L., & Vy, T. (2011). Evaluation the drivers of green supply chain management practices in uncertainty. *Procedia-Social and Behavioral Sciences*, *25*, 384-397.

Yang, C.L., Lin, S.P., Chan, Y.H., & Sheu, C. (2010). Mediated effect of environmental management on manufacturing competitiveness: An empirical study. *International Journal of Production Economics*, *123*(1), 210-220.

Yang, M. G., Hong, P., & Modi, S. (2011). Impact of lean manufacturing and environmental management on business performance: An empirical study of manufacturing firms. *International Journal of Production Economics, 129*(2), 251-261.

Yuan, C., Zhai, Q., & Dornfeld, D. (2012). A three dimensional system approach for environmentally sustainable manufacturing. *CIRP Annals-Manufacturing Technology*, *61*(1), 39-42.

Zailani, S., Jeyaraman, K., Vengadasan, G., & Premkumar, R. (2012). Sustainable supply chain management (SSCM) in Malaysia: Asurvey. *International Journal of Production Economics*, *140*(1), 330-340.