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Silicon Revolution: Sustainability Disclosures and Performance in the Semiconductor Manufacturing Industry (2010-2014)

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SILICON REVOLUTION:
SUSTAINABILITY DISCLOSURES AND PERFORMANCE IN THE SEMICONDUCTOR MANUFACTURING INDUSTRY (2010-2014)

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ABSTRACT

SILICON REVOLUTION:
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by Swarali H. Bhat

This exploratory work investigates the sustainability performance and reporting practices in 20 semiconductor companies from 2010-2014 using content analysis, survey, and interview methods. The sample consists of companies that are either integrated chip manufacturers (ICMs) or semiconductor foundries with annual net revenue of $0.2 billion to $55.9 billion. A sustainability matrix based on the Global Reporting Initiative guidelines assesses the reporting completeness. Sustainability performance is measured based on two factors, identification of trends in social and environmental data and adoption of 28 sustainability best practices specific to this manufacturing sector. The majority of the resource use and emissions data followed decreasing trends during 2010-2014. The study found ethical responsibility and concern for society and the environment to be the main motivations for sustainability reporting in this sector. A positive association between reporting completeness and the sustainability performance was observed, but based on the available data the causation could not be established.

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LIST OF ABBREVIATIONS

B2B	Business to business
BCP	Business Continuity Plan
CDP	Carbon Disclosure Project
CEP	Council for Economic Priorities
CSR	Corporate Social Responsibility
DRAM	Dynamic Random Access Memory
EHS	Environment, Health and Safety
EICC	Electronic Industry Citizenship Coalition
g	Gram
GHG	Greenhouse gas
GRI	Global Reporting Initiative
GWP	Global Warming Potential
ISO	International Organization for Standardization
IC	Integrated Circuits
ICM	Integrated Chip Manufacturer
KPI	Key Performance Indicator
Kg	Kilogram
LCA	Life Cycle Assessments
LEED	Leadership in Energy and Environmental Design
ODS	Ozone Depleting Substances
OEM	Original Equipment Manufacturer

OSHA	Occupational Safety and Health Administration
PFOS	Perfluorooctane Sulfonates Restriction
RCRA	Resource Conservation and Recovery Act
RMP	Risk Management Plans
RoHS	Restriction of Hazardous Substances
REACH	Registration, Evaluation, Authorization and Restriction of Chemicals
SD	Sustainable development
SIA	Semiconductor Industry Association
STEM	Science, Technology, Engineering and Mathematics
TBL	Triple bottom line
tCO2e	Tons of carbon dioxide equivalent
TOE	Ton of Energy
TRI	Toxic Regulatory Inventory
US	EPA United States Environmental Protection Agency
UPW	Ultrapure water
VOC	Volatile Organic Compound
WBCSD	World Business Council on Sustainable Development
WEEE	Waste Electrical and Electronic Equipment
WSC	World Semiconductor Council

Introduction

The term "semiconductors" covers a wide segment of products, such as chips, microprocessors, and integrated circuits (ICs) made from materials exhibiting properties intermediate between conductors and insulators. This unique property makes semiconductors a good medium for the control of electrical current. Silicon, along with thousands of other chemicals, is the primary raw material for producing ICs, chips, and microprocessors. Today, ICs have become ubiquitous due to their wide application in industries such as consumer electronics, automobiles, military, and telecommunications (PNPPRC, 1999; SIA, 2015; Wang and Chiu, 2013). The two-fold increase in global revenue generated by the semiconductor manufacturing industry from 2002-2014 (i.e., $140.7 billion in 2002 to $335.8 billion in 2014) indicates the flourishing nature of this industry (SIA, 2002 and 2014).

The birth of this successful industry dates back to 1930-1950. During this period, the bucolic landscape of the central Santa Clara Valley in California began to change with the advent of semiconductor startups. Eventually, the Santa Clara Valley was given a nickname, "Silicon Valley," as silicon was the main raw material in the manufacture of the chips and ICs (Jiang, Quan, and Zhou, 2008). The first semiconductor transistor and IC were conceptualized in the Silicon Valley in 1947 and 1950 respectively (Williams, 2004). Since then, Silicon Valley has created an economic whirlpool not only in the United States, but also across the globe.

Historically, most original equipment manufacturers (OEMs) in the Silicon Valley designed, fabricated, tested, and serviced their products in-house. The early 1980s

marked the era of knowledge transfer from the United States, which once monopolized the semiconductor manufacturing market, to other countries (Sustainability Accounting Standards Board, 2014; Tilton, 1970). Japan was the first to join the race in acquiring knowledge about these techniques and soon superseded the US in terms of total market share for a short while (1985-1990) (National Research Council, 1992; SIA Factbook, 2015). Multi-million dollar infrastructure investments and fast-paced product cycles induced the semiconductor manufacturing firms in the US to adopt new business models (Wang and Chiu, 2013). In addition, regular cycles of global financial slow-downs also played a significant role in outsourcing all or major divisions of manufacturing. The US OEMs employed contract manufacturers or fabrication units (fabs) in comparatively low-cost economies such as China, Korea, Japan, Taiwan, Singapore, and Malaysia to meet their semiconductor manufacturing needs.

The change of business models during the 1960s gave rise to three types of semiconductor companies: (1) fabs or integrated chip manufacture (ICM) firms that designed, manufactured, and sold semiconductor products; (2) semiconductor foundries that catered to the manufacturing demands of customers; and (3) fabless companies that designed in-house but employed outside fabs and foundries to manufacture products (International Trade Administration, 2015). Even though different market players have emerged in the semiconductor manufacturing domain over time, US firms still contribute a major share (SIA factbook, 2014; SIA, 2015). Figure 1 provides an overview of the percentage market share of the different countries.

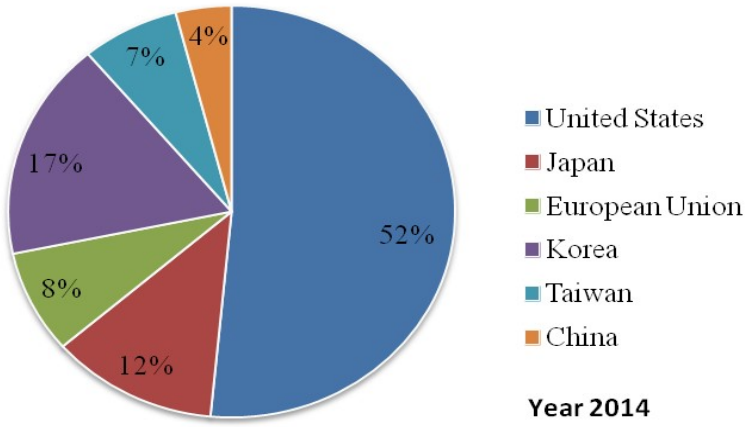

Figure 1. Global market share in semiconductor manufacturing. Adapted from *Made in America: The Facts about semiconductor manufacturing*, by F. Yinug, SIA, 2015.

Environmental Implications of Semiconductor Manufacturing

Chip manufacturing and packaging are the two main production units in the semiconductor industry (Villard, Lelah, and Brissaud, 2015). Chip manufacturing consists of five processes: design, crystal processing, wafer fabrication, final layering and cleaning, and assembly (PNPPRC, 1999; Wang and Chiu, 2013). On the other hand, the packaging process involves attaching a protective covering to the chip, which further protects the chip while mounting on a printed circuit board (PCB). This research studies social and the environmental impacts during the chip manufacturing and packaging process. For the sake of clarity, semiconductor manufacturing is the term used to encompass these two processes.

The wafer fabrication process is characterized by significant raw material use, high energy consumption, and extreme water-intensity. A typical chip manufacturing unit, or fab, uses several hazardous chemicals in the form of solvents, bases, acids, and metals. It is estimated that a single chip may use as many as 300 chemicals (e.g., sulfuric acid,

hydrochloric acid, hydrogen peroxide, trichloroethane, triclorомethane, perfluorooctane sulfonates, etc.,) throughout its manufacturing cycle (Villard at al., 2015). The extreme resource-intensity of the chip manufacturing is evident from the study conducted by Williams, Ayres, and Heller in 2002. According to this research, the production of a single 2 gram 32GB dynamic random access memory (DRAM) (a typical chip) requires 1600 grams of secondary fossil fuel, 72 grams of chemicals, 32,000 liters of water, and 700 grams of elemental gases (Williams et al., 2002). In the past 14 years since this study was conducted, the semiconductor chips have not only become more complex, but also have reduced in size according to Moore's law. Moore's law states that the number of transistors per square inch of an IC doubles every year (Intel website, 2016). It is beyond doubt that the increasing complexity of the chips has direct impact on the use of hazardous chemicals and waste production. As a result, these processes have amplified the risks to both human health and the surrounding environment. The clean rooms, which ensure a dust-free environment for semiconductor fabrication processes, are extremely energy intensive and require high quality, pure water. Electricity is by far the most utilized energy source that powers the actual manufacturing equipments along with the administrative offices in a semiconductor company. Typically, electricity caters to nearly 80% of the fabs' energy needs (SK Hynix Sustainability report, 2014). Interestingly, nearly 65% of electricity in a fab is consumed in processes other than the actual manufacturing (Lawrence Berkeley National Laboratory, 2000).

Life Cycle Assessments (LCAs) conducted for the semiconductor industries have differentiated the environmental impacts during the different phases such as the

manufacturing, consumer use, and disposal phase. Problems such as greenhouse gas (GHG) emissions, resource use, and water eutrophication are common during the manufacturing stage while e-waste and water toxicity are the challenges faced during the product disposal phase (Villard at al., 2015). Thus, considering the entire lifecycle, the environmental problems of this industry are global warming, resource depletion, water stress, air emissions, and waste generation (Lu, Wang, and Lee, 2013). Higgs, Cullen, Yao, and Stewart (2009) found that the GHG emissions are plentiful during the product use phase as compared to the semiconductor manufacturing processes. Out of the GHG emissions produced during the semiconductor manufacturing phase, nearly 54% are contributed by the actual manufacturing processes (Lu et al., 2013). The semiconductor industry utilizes a business to business (B2B) model and hence, there is minimal interaction with the end customers. Consequently, there is minimal study on the social and environmental aspects of this industry (Villard at al., 2015).

In the past, Silicon Valley had a high concentration of OEM facilities that manufactured semiconductor products. In 1982, the incident of trichloroethane (C_2HCl_3) and dichloroethane ($C_2H_2Cl_2$) leaching into the groundwater led to detrimental reproductive health concerns in the neighboring areas of San Jose, California (Kim, Kim, and Paek, 2014). This contamination acted as a catalyst for enforcing strict government regulations against polluters and also alerted stakeholders about the potentially disastrous effects of this industry. Eventually, the semiconductor company spent multi-millions of dollars on the site clean-up and fines (Siegel, 1995). According to the United States Environmental Protection Agency (US EPA) (2014), California has highest number of

Superfund sites,[1] which are located in the heart of Silicon Valley at Palo Alto, Sunnyvale, Cupertino, and Mountain View. Initially, the health impacts of this industry were limited to the UK and the US, but due to the globalization of supply chains, these impacts were also "outsourced" to Asian countries such as Thailand, India, Taiwan, China, and Malaysia (Kim et al., 2014). Such tragic incidents demonstrate that the operations of a semiconductor company have the potential to impact not only the environment, but also the society at large.

As mentioned earlier, the semiconductor industry uses many organic solvents, acids, and bases. These chemicals possess a variety of characteristics that range from being simple irritants to carcinogens, which may lead to spontaneous abortions, reduction in fertility rates, and birth deformities (Kim et al., 2014). The radiation emitted during manufacturing has been claimed to cause cancerous growths in some fab employees (LaDou and Rohm, 1998). In contrast, a study conducted by the Semiconductor Industry Association (SIA) (2001) in the US found no association between working in a semiconductor fab and higher risks of cancer. Electronic Industry Citizenship Coalition (EICC) is an organization in the electronic industry space that introduces industry-wide standard on social, environmental, and ethical issues (EICC, 2016). EICC is a major player in the electronics industry that advocates solutions to reduce the social and environmental impacts of this industry. The Self-Assessment Questionnaire (SAQ) developed by the EICC is a self-reporting template used by the semiconductor

[1] Superfund site is the name given to the environmental program established to address abandoned hazardous waste sites. It is also the name of the fund established by the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA statute- CERCLA overview: US EPA, 2014).

manufacturing companies to assess gaps in the operational practices. According to a report published by the EICC, non-standard working hours and trafficked and bonded labor are the key challenges faced by this industry even in the twenty first century. Thus, based on these findings, the semiconductor manufacturing industry has several environmental, health and safety concerns that affect the society in which the company operates.

As a response to the finite availability of resources and pollution risks during semiconductor manufacturing, firms began to incorporate sustainable measures to ensure a steady supply of resources for present and future use. In the semiconductor industry, stakeholders are keen in understanding the initiatives adopted by companies to address environmental concerns such as GHG emissions, resource use, and water eutrophication (Villard at al., 2015). "Stakeholder" is the common term which encompasses employees, suppliers, contractors, customers, government organizations, non-government organizations, academia, and students who are affected by the activities of the organization. Usually, the vision of corporate leadership and business strategy decides the priority of addressing social and environmental impacts of the company. There are a number of different approaches, such as government regulations and voluntary initiatives, which can improve the corporate sustainability. However, this research investigates the sustainability in the semiconductor manufacturing industry through the analysis of data presented in corporate sustainability reports of companies. The latter section describes a brief history behind the development of sustainability reporting.

History behind Sustainability Reporting

The Brundtland report (1987) first popularized the concept of sustainable development, which soon became the catchword in many political and business communications. Sustainable development (SD) is defined as, "development that meets the needs of the present, without compromising the needs of future generations" (World Commission on Environment and Development, 1987, pp. 43). In 1992, the Rio Declaration further formalized this concept by recognizing the need for 27 principles related to social, environmental, and economic well-being (UNEP, 1992. Chap.1). SD was not possible without the active collaboration of government regulators, policy makers, corporations and private entities (WCED, 1987). According to the Brundtland report (1987), corporations that play an active role in economic development should also participate in the process of SD. In 1992, World Business Council on Sustainable Development (WBCSD) addressed the topic of corporate sustainability and thus bridged the gap between SD and the role of corporations.

Corporate sustainability is an application of the SD concept specific to the business domain and involves strategically managing and integrating economic progress, environmental protection, and social responsibility. A representative definition of corporate sustainability is, "the adoption of business strategies and activities that meet the needs of the enterprise and its stakeholders today, while protecting, sustaining, and enhancing the human and natural resources that will be needed in the future" (IISD, 1992).

Over the years, awareness about sustainability has increased not only in the corporate sector, but also among stakeholders such as employees, customers, suppliers, contractors, investors, media, students, academia, governmental agencies, and non-profit organizations. Initially, companies used financial indicators to showcase the firm's performance, but as cognizance about environmental and social concerns among stakeholders began to grow, company executives began to be bombarded with queries on corporate social responsibility (CSR). Hence, a new trend of publishing sustainability reports that integrated data about social, environmental, and economic parameters began to emerge in the corporate sector (Krajnc and Glavic, 2004). These reports contain quantifiable data about social, environmental, and economic impacts of a company and inform stakeholders about the firm's effectiveness and performance.

According to Unerman, Bebbington, and O'Dwyer (2007), the perception of sustainability reporting has gradually transformed from a system that reported about employee welfare to the present all-inclusive sustainability approach. Records of CSR reporting date back to the mid-1880, when companies, such as US Steel and Broken Hill Proprietary (BHP) mining, published limited information about employee well-being (Gutherie and Parker, 1989). It took about a century for the early employee-based reporting systems to transform into social reporting that contained some information about environmental aspects such as waste generation and energy usage. The Exxon Valdez oil spill of 1989, which affected 1,300 miles of shoreline, proved to be a turning point in the history of environmental reporting. This event led to the introduction of the first ever environmental reporting guidelines by the Coalition for Environmental

Responsible Economies i.e., CERES (KPMG, 2010). Further, these reporting guidelines were fine-tuned by SustainAbility and United Nations Environment Protection (UNEP) during the 1990s. Finally, the first well-defined guidelines, based on the triple bottom line (TBL[2]) approach, were released by the Global Reporting Initiative (GRI) in 2000 (KPMG, 2010).

Reporting guidelines published by organizations such as the GRI, International Organization for Standardization (ISO) (ISO 26000 and ISO 14000 series), Sustainability Accounting Standards Board (SASB), and Social Accountability International (SA 8000) are popular frameworks that standardize sustainability reporting in most industries. Due to the framework provided by these guidelines, companies can describe their social, environmental, and economic performance in greater detail. The diverse expectations of stakeholders, cost constraints, and time requirement makes it impossible for companies to follow all desired sustainability reporting guidelines in their reports. In addition, different sectors, such as information technology, semiconductors, oil and gas, paper and pulp, banking, and educational institutions differ with operations and impacts. Thus, guidelines suitable for one industry might not suit the other. The framework developed by the GRI is the most comprehensive sustainability reporting guideline available today (Clarkson, 2008; Daub, 2007; Lozano 2013; Roca and Searcy, 2012; Tschopp and Nastanski, 2013). The GRI guidelines are generic and can be applied to any sector. The growing popularity of the GRI guidelines is evident through the 108% increase (2,545

[2] The term triple bottom line (TBL) was coined by John Elkington in 1994. Elkington suggests that organizations must consider social and environmental responsibility, along with economic profitability for them to achieve long-term sustainability (Elkington, 1997)

reports in 2010 compared to 5,315 reports in 2014) in the total number of reports published from 2010-2014 using the GRI framework (GRI, 2015).

Over the past 16 years since their conceptualization, GRI guidelines have been regularly revised to meet the priorities of the reporters and stakeholders. The most current, fourth generation G4 guidelines of the GRI were published in May of 2013. According to GRI, a good *quality* report must possess characteristics such as balance, comparability, accuracy, timeliness, clarity, and reliability (GRI, 2013). A sustainability report must provide information on the positive and negative performance of the company in a well-balanced and fair manner (GRI, 2011). Some sectors such as construction and real estate, food processing, oil and gas, mining and metals, electric utilities, airports, financial services, media, and NGO have sector-specific supplements along with the generic GRI guidelines. The industry under study (semiconductor manufacturing sector) has no such sector-specific supplement. This research assesses the completeness of sustainability reporting using a sustainability matrix based on the GRI G3.1 and G4 guidelines. Completeness in this context refers to balanced and reasonable representation of social and environmental parameters relevant to the semiconductor industry through quantitative, descriptive, and historical data.

During the early 1990s, the practice of sustainability began to grow steadily, and companies used different nomenclatures to name their CSR reports. Some of the common names by which these reports are published are “sustainability report,” “corporate sustainability report,” “corporate social responsibility report,” “citizenship report,” and “social and environmental report” (Roca and Searcy, 2012). Each of these

reports addresses sustainability, but the central theme of each report varies with the name. For uniformity and ease of understanding, this research will use the generic term "sustainability report" to address all the different names by which these reports are published. The GRI (2013) defines a sustainability report as a report published by a company describing the social, economic, and environmental impacts of day-to-day activities of the organization.

The main objective of this study is to assess the completeness of social and environmental disclosures with respect to the balance, comparability, accuracy, timeliness, clarity, and reliability of data (GRI, 2013). In addition, it is necessary to gauge the performance of companies based on the adoption of sustainability, best practices, and trend analysis of social and environmental data.

Companies have different approaches to imbibing sustainability into their core business. Some companies believe employee volunteering to be the best way to ensure social development, while some firms invest in employee training, youth (K-12) programs, and STEM (Science, Technology, Engineering, and Mathematics) education. Since the approach to adoption of sustainability programs varies across companies, the data reporting styles and formats are also different. For example, some firms present historical data trends for five years in the reports, while some showcase only one year of data.

This research study is conducted at San Jose State University, situated in the heart of Silicon Valley, the birthplace of the consumer electronics industry. Today, the semiconductor industry is the backbone of every industry that uses electronic

components. As stated earlier, there are tremendous social and environmental impacts of this industry, and the high concentration of the Superfund sites in Silicon Valley is a pertinent example of this fact. The location of this research study and the impacts of this multi-billion dollar industry are some of the motivations behind this study.

Literature Review

Report completeness, sustainability performance, and motivation behind sustainability reporting are the three important aspects of this research. Researchers have assessed sustainability performance based on data presented in inventories such as Council for Economic Priorities (CEP), Toxic Regulatory Inventory (TRI), and Ministry of Environment (MoE) National Pollution Release Inventory Program. In addition, the assessment of the relationship between report completeness and sustainability performance has followed different directions. There are numerous factors that motivate sustainability reporting, but green brand reputation and stakeholder pressures are by far the key drivers (KPMG, 1999; Patten and Zhao, 2014). The following sections provide a detailed overview about past research conducted on sustainability performance and reporting, along with factors motivating sustainability reporting.

Corporate entities play a vital role toward economic functions in society by providing services, employment, and wealth to its stakeholders (Martinez, Fernandez, and Fernandez, 2015). Stakeholders are pillars of a company's long-term success, and, therefore, it is the responsibility of every company to keep its stakeholders well-informed about internal processes, involved risks, and mitigation strategies (Perrini and Tencati, 2006). Meeting stakeholder expectations also improves financial profits and provides a competitive advantage to the company (Harrison, Bosse, and Philips, 2010; Martinez et al., 2015).

Problems such as social disparities, environmental degradation, and economic uncertainties have necessitated companies to take responsibility for their actions, as they

affect stakeholders and the environment. Based on these impacts, companies began to address the social and environmental aspects of their business models beyond economic profitability. Dyllick and Hockerts (2002), and van Marrewijk (2003) define corporate sustainability as meeting the needs of primary and secondary stakeholders without compromising the company's ability to fulfill the needs of future customers. Companies adopt different communication channels to address concerns raised by the stakeholders. Over the years, publishing detailed reports about sustainability initiatives has become a one-stop solution to meet the diverse informational interests of different stakeholders. Disclosure through reports is often seen as a dialogue between stakeholders and the company (Gray, Kouhy, and Lavers, 1995)

According to the GRI guidelines (2015), stakeholders have varying interests in the sustainability data disclosed publicly by a company. Since sustainability reporting is voluntary in most countries, companies have the freedom and flexibility of disclosing selective, sector-specific data using reporting guidelines of their choice. However, the majority of the historical studies on sustainability reporting are based on GRI guidelines, due to their multi-pronged approach that grades three aspects of sustainability equally (Clarkson, 2008; Daub, 2007; Lozano 2013; Roca and Searcy, 2012). On the contrary, Daub (2007) mentions that this flexibility in reporting may result in disclosure of biased strategic information which helps the company to retain its public image.

The practice of sustainability reporting is primarily driven by external pressures exerted by stakeholders who are interested in understanding the company's social, environmental, and economic risks and the associated management practices (Patten and

Zhao, 2014). Researchers are progressively studying the motivation behind the adoption of sustainability practices across the globe. However, the factors that motivate adoption of sustainable corporate practices are usually independent from the factors that favor implementation of sustainability reporting. Sustainability reporting is a voluntary practice in most parts of the world (Dilling, 2010; Kolk, Walhain, and Wateringen, 2001). Despite this fact, countries such as Japan, US, Finland, UK, Malaysia, Denmark, and Netherlands have some type of mandatory environmental reporting in place (Ernst & Young, 2014). Countries such as Sweden, Russia, Singapore, and Norway are in the process of passing regulations that mandate sustainability reporting by companies of a certain size and industry type. Furthermore, researchers such as Boysen (1997), Jones, Hillier, and Comfort (2009), KPMG (1999), and Willard (2005) have found that internalization of corporate sustainability reporting practices is prominently driven by factors such as customer and peer pressure, green brand reputation, investor relations, and employee retention. Similarly, inclusion in sustainable investment ranking indices has a positive impact on the share value of a company, if the company publishes sustainability reports (Whaley, 2013). Sustainability reporting is often the best way to communicate information about internal programs that aim to achieve social equity, environmental conservation, and economic profitability. It is reasonable for stakeholders to expect companies to communicate true and unbiased information through their reports. Some incidents during the early 1980s caused public outrage because companies intentionally published misleading information about their environmental activities to "greenwash" and create a false environment-friendly image (Tschopp and Nastanski, 2013). When a

company deliberately provides misleading information to maintain its environmentally responsible image, it is referred to as greenwashing (Ramus and Montiel, 2005)

In contrast, there are a number of counterarguments about the effectiveness of sustainability reports. Leinaweaver (2015) criticized that firms waste time and money in the compilation of these reports. The practice of sustainability reporting has reached a plateau where stakeholders are no longer interested to read the lengthy reports (Leinaweaver, 2015). Instead, companies prefer using innovative media, such as websites, brochures, and videos to portray the social and environmental initiatives (Isenmann, Bey, and Welter, 2007). In addition, factors such as cost constraints, workforce delegation, and disinterested stakeholders deter companies from publishing sustainability reports (Kolk, 2010). According to a study about sustainability reporting in the Global Fortune 250 companies, Kolk (2002 and 2003) found that internalized factors such as cost reduction and efficiency were greater motivators than external factors such as government regulations or incentives. Companies are also concerned that over-disclosure of social and environmental information may trigger public scrutiny, resulting with legal implications (Kolk, 2010). As a result, sustainability reporting is supported by two philosophies; one school of thought conceives reporting as a powerful tool that ensures effective stakeholder communication while the other criticizes this practice due to the purposeful greenwashing and non-transparency (Patten and Zhao, 2014).

Sustainability performance is often achieved by incorporating state of the art programs and initiatives that reduce a firm's social and environmental impacts and ensure continuous economic profitability. Top management plays a key role when formulating

successful strategies and policies that support effective sustainability initiatives (Epstein and Roy, 2001). Most studies in the past have gauged sustainability performance based on the adoption of key performance indicators (Kylili, Fokaides, and Jimenez, 2016), and very few have based their analysis on adoption of best practices (Tsoutsos, Tournaki, Paraiba, and Kaminaris, 2016). Similarly, analyzing data trends about environmental and social parameters also provides a fair estimate of the effectiveness and maturity of the programs aimed to achieve environmental conservation and social well-being. Business models of companies and their social and environmental impacts differ extensively across industries. Based on these observations, this research examines sustainability performance of companies comprised of a single industry (i.e., semiconductor manufacturing), as their operations, resource use, and impacts are identical.

Past Research in the Field of Sustainability Reporting

Sustainability reporting is usually a very time intensive and expensive process. It is usually the forte of large companies, given the availability of workforce and financial resources (Herbohn, Walker, and Loo, 2014). In spite of this, small and medium sized companies are also steadily adopting this practice. Companies are pressured to follow all commitments made through these reports as stakeholders critically scrutinize this data (Brammer and Pavelin, 2008).

Daub (2007) conducted a first-of-its-kind qualitative and quantitative study on sustainability reporting. The highlighting feature of this study was the sustainability matrix developed for assessing the completeness of sustainability reporting. This sustainability matrix was based on 33 parameters derived from the GRI G3 guidelines.

The sustainability reports of 76 large companies headquartered in Switzerland were selected from various sectors such as banking, oil and gas, paper and pulp, etc. Each report was graded from 0 to 3 depending on the data availability, depth and coverage. Table 1 describes how the 33 parameters were divided into four broad categories such as- (A) context and coverage, (B) policies, management systems and stakeholder relations, (C) dimensions of performance- economic, environmental, social and integrated, and (D) transparency and general view. Given the importance of performance parameters (category C) for this study, the economic, environmental, social and integrated sub-categories were given double weight (i.e., graded from 0-6) as compared to categories A, B and D (graded from 0-3). In addition to the quantitative study of sustainability reports using the sustainability matrix, the research team also conducted interviews with the sustainability managers of selected companies to get a deeper understanding of the sustainability reporting practices.

Table 1
Parameters considered in original sustainability matrix. Adapted from *Assessing the quality of sustainability reporting: An alternative methodological approach*, by C. H. Daub, 2007

Original category		No.	Constituent parameters
A	Context and coverage	1	Basic information about company and report
		2	CEO/President testimonial
		3	Business plans and vision
		4	External business and sustainable development trends
B	Policies management systems and stakeholder relations	5	Code of conduct and company philosophy
		6	Economic policies
		7	Environmental policies
		8	Social policies
		9	Integration of sustainability in management systems
		10	Risk identification and management
		11	Stakeholder communication systems
C	Dimensions of performance		
C1	Economic performance	12	Key financial information
		13	Employee benefits and compensation
		14	Customer and suppliers satisfaction program
		15	Community and local economic growth
C2	Environmental performance	16	Quantity of resources consumed
		17	Qualitative information about resources
		18	Air pollution
		19	Water pollution and waste generation
		20	Biodiversity
C3	Social performance	21	Human resource management and corporate culture
		22	Health and safety management system
		23	Employee knowledge enhancement
		24	Labor and human rights
		25	Regional and global social development
C4	Integrated performance	26	Economic, environmental, and social key-figures normalized with respect to production unit
		27	Economic, environmental, and social key-figures normalized with respect to net revenue
D	Transparency and general view	28	Reliability and transparency of data
		29	Reliability with respect to environmental data
		30	Reliability with respect to social data
		31	Comparability
		32	User-friendliness and organization of report
		33	Structure and language of report

The sustainability matrix developed by Daub (2007) is unique due to its applicability to any sector and easy data extraction from publicly available reports. The findings of this study by Daub (2007) indicated that quantitative data representation on social and environmental aspects was difficult and tedious. Some of the shortcomings of this study are, (1) sample consists of companies from multiple sectors, and a fair comparison of sustainability reports is not possible as the impacts and resource use differ in each sector; (2) only large companies are considered; and (3) only the completeness of the sustainability reporting is assessed using the sustainability matrix, while the sustainability performance is not addressed. Reporting and performance are two independent facets of sustainability. Sustainability performance needs to be assessed to understand the implementation of sustainability initiatives and their success through results or trends.

Docekalová and Kocmanová, (2015) mention that corporate success must be measured not only by the economic profitability, but also by its sustainability, performance, and accountability. In the corporate environment, environmental performance can be assessed using resource consumption, energy usage, waste production, and pollution (Ranganthan, 1998). Hsu et al. (2011) developed a sustainability balance scorecard (SBSC) based on the fuzzy delphi method (FDM) and the analytical network process (ANP) that involve content analysis of the sustainability reports of semiconductor companies. The results of this study indicate that sustainability performance in a semiconductor company could be measured using profits, green innovation, green image, customer satisfaction, and top management's interest to incorporate sustainability (Hsu et al., 2011). Ranganthan (1998) also mentions factors

such as employment, ethics, community engagement, and social impacts of manufacturing to be key representations of a company's social performance. In the past, the environmental performance of companies is assessed using the waste generation and pollutant release data presented in CEP, TRI, and MoE's National Pollution Release Inventory Program (Bewley and Li, 2000; Cowan and Deegan, 2010; Ingram and Frazier, 1980). Sustainability performance has also been assessed by the interconnection of the three sustainability components, (i.e., economy, society, and environment) (Ranganthan, 1998) or through green growth (Saufi, Daud, and Hassan, 2016).

Based on this broad set of information specific to sustainability performance, sharing knowledge about social and environmental best practices adopted by individual semiconductor manufacturing companies would definitely prove to be a mutually beneficial practice for the industry consortium (ICT, 2010). Incorporating best practices can also boost a firm's performance (Reijers and Liman-Mansar, 2005). In this context, sustainability best practices are the initiatives or measures adopted by a company to improve social and environmental impacts of its operations. EICC (2016), Hsu et al., (2011), and SASB (2014) described different sets of best practices specific to the semiconductor industry. Table 2 provides a list of 28 best practices which are the priority issues in the semiconductor industry both internally (i.e., for management) as well as externally (i.e., for stakeholders).

Table 2
Sustainability best practices specific to the semiconductor industry (EICC, 2016; Hsu et al., 2011; SASB, 2014)

1.	Product compliance certification
2.	Long term sustainability goals
3.	Water conservation projects
4.	Materiality analysis for sustainability KPI identification
5.	Employee and customer survey
6.	Reports based on GRI guidelines
7.	Sustainability benchmark certificates
8.	Diversity and inclusion
9.	EHS policy and department
10.	Energy efficiency projects
11.	Life cycle assessment
12.	Supplier responsibility
13.	Facility audits
14.	Green transportation
15.	Conflict minerals policy
16.	Risk management system
17.	Reduction and reuse of ultra pure water
18.	GHG emissions and elimination of ODS
19.	Normal working hours
20.	Fines and violations
21.	Reusable packaging
22.	Human rights policy
23.	Sustainability strategy and department
24.	Waste reduction projects
25.	CDP disclosure and carbon-water footprint
26.	Fair wages
27.	Third party assurance of sustainability report
28.	Green building certification

These best practices range from sustainability initiatives from a regulatory standpoint (e.g., WEE, RoHS, REACH certifications) to advanced practices such as LCAs or the reuse of ultrapure water (UPW). Even though the adoption of these best practices indicate the company's advanced approach to achieving greater sustainability performance, it is vital to analyze the success or failure of these initiatives through analysis of data trends.

Normalized data, absolute data, and historical data are good indicators of the sustainability performance (Dantes, 2006). Normalized data ensures an apple to apple comparison while absolute data represents overall resource use and its impact. Similarly, historical data gives the reader an overall perspective of the past and present approach to environmental and social aspects even though it may not guarantee future success. As mentioned earlier, sustainability reporting and sustainability performance are two interdependent yet independent aspects of sustainability in any corporate setting.

In light of this discussion on sustainability best practices, Brusman (2009) mentions sustainability adoption in a company to be a linear process that goes through five phases as depicted in Figure 2.

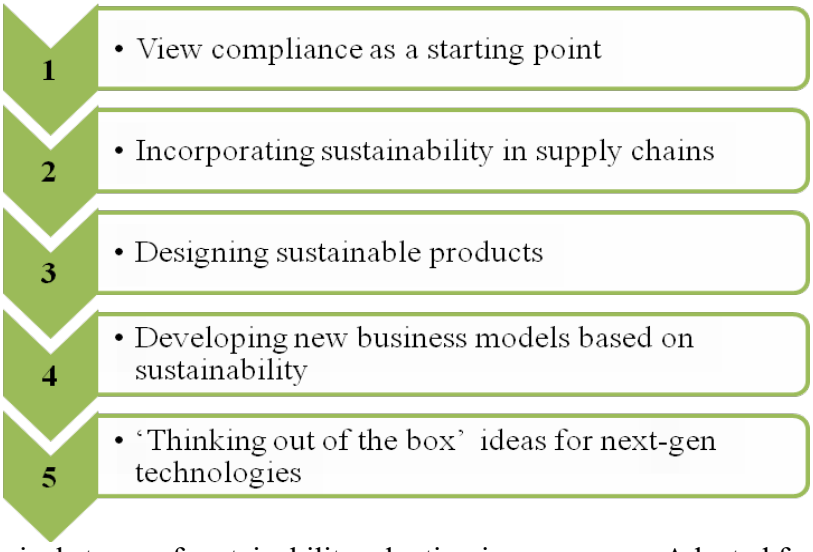

Figure 2. Typical stages of sustainability adoption in a company. Adapted from *Working resources*, by M. Brusman, 2009.

According to Brusman (2009), sustainable measures are first introduced in the company to meet certain regulatory compliances. As these measures mature, companies introduce the same practices into their supply chains for better resilience and adaptability.

Further, sustainable products may be developed by using green manufacturing techniques, state-of -the-art knowledge about raw materials and waste minimization processes. Ultimately, new business models are developed such that sustainability takes the center stage.

Relationship between sustainability performance and disclosures. Brammer and Pavelin (2008) found a positive relationship between report quality, company size, and tendency to pollute. Similarly, companies with greater public visibility and pollution legacy lead in voluntary disclosure of sustainability-related data (Alonso and Almeida, 2012). In addition, Herbohn, Walker, and Loo (2014) mention that companies with good sustainability performance usually publish good quality data in their reports. Similarly, a study about sustainability reporting trends by Estonian (country in the Baltic region of Northern Europe) companies listed on the Tallinn stock exchange discovered that factors such as environmental training, seminars about CSR, and use of standardized reporting guidelines resulted in good quality of sustainability reports (Gurvitsh and Sidorova, 2012).

Assessing environmental performance through content analysis of sustainability reports has been explored widely. The first analysis about environmental performance using publicly available data was conducted by Ingram and Frazier (1980) using content analysis of sustainability data from 40 companies rated by the CEP. This study found no significant relationship between disclosures and the level of environmental performance. Similar results were observed by Freedman and Wasley (1990) and Wiseman (1982), who conducted a multi-sectoral assessment of sustainability disclosures using mixed

methods in 26 companies from environmentally sensitive industries such as mining, paper and pulp, and oil and gas.

However, Bewley, and Li (2000) found a negative association between disclosures and environmental performance. This study considered participation in the MoE's National Pollution Release Inventory Program as an indicator of the environmental performance. Similarly, another multi-sectored study by Patten (2002) followed the findings of Bewley and Li (2000) when environmental performance was based on the toxic releases reported in US EPA's TRI registry. A study by Cowan and Deegan (2010) analyzed the trends during the implementation stage of the National Pollution Inventory in Australia and found a negative relationship between environmental performance and quality of disclosures.

In contrast to the above trends, a positive relationship was found between levels of voluntary environmental disclosures and performance when reports from the five most polluting industries in the US were analyzed using the pollution data from US EPA's TRI registry (Clarkson, Overell, and Chapple, 2008). Similarly, when environmental performance was judged by the amount of waste generated, a positive association between disclosures and performance was observed (Al-Tuwaijri, Christensen, and Hughes, 2004). The study conducted by Herbohn, Walker, and Loo (2014) is the only research conducted till date that analyzes the relationship between sustainability performance and sustainability disclosures. Interestingly, this research study conducted for the mining and energy sector revealed a positive correlation between the two parameters. Based on these studies, there is no consistent trend between disclosures and

performance, and a possible explanation of this variation of trends could be the heterogeneity of parameters analyzed in each research study. In addition, the sample of these studies consists of industries from multiple sectors which vary with respect to their resource use and impacts.

Researchers have investigated disclosures of sustainability parameters through content analysis across sectors and geographical regions (Al-Tuwaijri et al., 2004; Asif, Searcy, Santos, and Kensah, 2013; Clarkson, Li, Richardson, and Vasvari, 2008; Dagiliene and Mykolaitiene, 2015; Daub, 2007; Gherardi, Guthrie, and Farneti, 2014; Hsu et al., 2011; Ingram and Frazier, 1980; Patten, 2002; Roca and Searcy, 2012). Sustainability reporting trends are also extensively studied for organizations in developed nations, such as the United States (Freedman and Wasley, 1990; Hughes, Anderson, and Golden, 2001; Patten, 2002), Canada (Bewley and Li, 2000), Australia (Cowan and Deegan, 2010; Herbohn, Walker, and Loo, 2014), and Europe (Daub, 2007; Gurvitsh and Sidorova, 2012; Lozano, 2013), and in developing economies, such as India (Kumar, Gunasekaran, Singh, Papadopoulos, and Dubey, 2015) and Bangladesh (Sobhani, Amran and Zainuddin, 2012). Sustainability reporting has emerged as a widespread global practice.

Sustainability reporting trends are examined extensively in sectors such as oil and gas, information and communication technology (ICT), pharmaceutical (Krajnc and Glavic, 2005), steel and paper (Freedman and Wasley, 1990; Wiseman, 1982), manufacturing (Hughes et al., 2001), and banking (Sobhani, Amran, and Zainuddin, 2012). Each of these researchers has analyzed the relationship between sustainability

performance and reporting quality. Assessment of this relationship provides a comprehensive overview of the company's approach to sustainability practices and its willingness to share information with its stakeholders. In the banking sector, social disclosures were comparatively less as compared to the environmental and economic disclosures (Sobhani, Amran, and Zainuddin, 2012). Environmental disclosures by environmentally sensitive industries are usually greater than those by non-sensitive industries (Al-Tuwaijri et al., 2004). In the mining sector, larger companies reported more social data as compared to small enterprises, while no significant relationship was observed in environmental disclosures (Villiers, Lowa, and Samkin, 2014).

According to Clint Wheelock of Pike Research, "… the closer the company's business is related to consumer electronics, the higher its CSR score" (Navigant research report, 2011). Most of the leading consumer electronic brands are adopting sustainable practices into their product design, manufacturing, logistics, customer use, and end of life management (Navigant Research report, 2011). Semiconductor manufacturers have a business to business (i.e., B2B) model, which indicates minimum interaction with end customers, unlike the consumer electronic industry. There is significant scholarly documentation showing the relationship between disclosures and environmental performance of firms from different industrial sectors (Freedman and Wasley, 1990; Hughes et al., 2001; Krajnc and Glavic, 2005; Wiseman, 1982) However, very few studies, such as Hsu et al., (2011), Roberts Environmental Center (2012), and Wibowo and Deng, (2013) have evaluated either the sustainability disclosures or sustainability performance in the semiconductor manufacturing industry. Roberts Environmental

Center used the Pacific sustainability index to analyze sustainability reports of top semiconductor companies. The findings of this study indicate that the majority of the companies reported on GHG emissions, energy use, recordable incident rates, water use, and waste recycled, while the minimum information was furnished for parameters such as office waste recycling, soil contamination, renewable material use, health and safety violations, and particulate matter (Roberts Environmental Center, 2012).

Social reporting. Studies that assess trends in social reporting are growing steadily (Morioka and Carvalho, 2016). Unerman (2000) tabulated the different methods adopted by 25 researchers for evaluating the social disclosures and performance of companies. This overview indicated that the CSR of companies was measured using quantifiable information such as number of documents, words, sentences, paragraphs, pages and/or percentage of pages of the entire document (Unerman, 2000). Early studies (1978-1998) analyzed annual reports, environmental reports, corporate brochures, advertisements and/or other communication documents of companies to understand social performance (Harte and Owen, 1991; Setyorini and Ishak, 2012; Zeghal and Ahmed, 1990).

Owing to this large gap in literature, this exploratory work uses a combination of content analysis, surveys, and interviews to assess social and environmental performance in the semiconductor industry, along with completeness in sustainability reporting. Innovative and interactive media such as interviews and surveys provide insider information about the company's sustainability. Several studies conducted by researchers such as Boysen (1997), Jones et al. (2009), Kolk (2002 and 2003), KPMG (1999), Whaley (2013), and Willard (2005) laid the base for creating the survey

document used to understand factors motivating sustainability reporting in the sample companies. The interview questionnaire was prepared based on past research on corporate sustainability and consultation with industry experts.

This literature review reiterates that sustainability reporting and performance have been comprehensively assessed in several sectors that are polluting (e.g., oil and gas, paper and pulp etc.) as well as non-polluting (e.g., hotels, banks etc.). Despite the fact that the semiconductor industry has a high impact on society and the environment, it is one of the most understudied industries among the high impact cohort (Villard, Lelah, and Brissaud, 2015). The semiconductor manufacturing industry is a polluting industry that warrants more environmental disclosures and improved performance. Based on this gap in research, this study investigates the trends in sustainability performance and completeness in sustainability disclosures for the semiconductor manufacturing sector.

Problem Statement

Silicon Valley, the birthplace of the semiconductor industry, has a toxic legacy evident from the high concentration of Superfund sites that are majorly located at sites that manufactured semiconductors earlier (Pimentel, 2004). According to the American Institute of Certified Public Accountants (AICPA, 2014), the statement of position on environmental remediation liabilities (SOP-96) mandates that US companies with environmental liabilities publish information on remedial action in their annual reports. Since annual reports usually cater to the economic performance of the company, it is reasonable to believe that sustainability reports can act as a powerful tool to portray initiatives adopted to reduce and reverse the environmental impact of its operations.

Secondly, the number of semiconductor manufacturing facilities in Silicon Valley today is minimal. The "off-shoring" of chip manufacturing has also "outsourced" the environmental and social impacts of this industry to low labor cost economies around the world. An early understanding of the initiatives undertaken in these economies can help track their performance to prevent social and environmental disasters and lawsuits, similar to those in Silicon Valley.

In addition, the semiconductor manufacturing industry impacts biodiversity. Hsinchu Science Park in Taiwan is one of the biggest conglomerates of semiconductor manufacturers in Taiwan; it is often referred to as the Silicon Valley of Taiwan. The high levels of tungsten and other heavy metals found in Keya Creek (Taiwan), which receives treated wastewater from the Hsinchu Science Park, is an excellent example depicting the impacts of this industry on the aquatic ecosystems (Hsu et al., 2011). Based on this observation, there is a strong need to study the ecological responsibility of semiconductor manufacturing companies.

Lastly, historical studies have considered sustainability reporting and social and environmental performance trends in the top listed companies as presented by Fortune magazine, Forbes magazine, San Jose Mercury News, Dow Jones Sustainability Index, etc. Interestingly, very few studies have been conducted till date to explore the sustainability performance and report completeness in firms that are small or medium sized and are late adopters of sustainability practices. Understanding the completeness of data presented in the sustainability reporting of semiconductor manufacturing firms along with assessing their social and environmental performance are the two key motivations of

this thesis research. Additionally, the motivation behind publishing sustainability reports in this industry is also unexplored till date.

Objectives of the Study

This research was initiated to achieve three primary goals: evaluation of report completeness, assessment of sustainability performance, and understanding factors that motivated sustainability reporting in the sample semiconductor manufacturing companies. There exists abundant literature about factors that motivate adoption of sustainability reporting, but motivations specific to the semiconductor sector are extremely scarce and nearly absent. In addition, there exists a paucity of literature that investigates the completeness of sustainability reporting together with sustainability performance in the semiconductor manufacturing sector. Few LCAs have been conducted till date, but an in-depth study on this aspect is not observed for the industry under consideration. Although sustainability is a complex union of environmental, economic, and social aspects, this study mainly addresses the environmental and social incline of semiconductor manufacturers, because economic prosperity of companies has been discussed extensively in past literature. Therefore, this research study shall fill the gap in the literature about sustainability practices in the semiconductor manufacturing sector. The exploratory research addresses the following questions:

Q1. What are the key factors that motivate adoption of sustainability reporting in the sample semiconductor manufacturing companies?

Q2. How complete is the publicly available disclosure data presented in the corporate sustainability reports?

Q3. How do the companies perform based on adoption of sustainability best practices and analysis of patterns in social and environmental data from 2010-2014?

Methods

Content analysis of sustainability reports, surveys and interviews with the sustainability managers are used to answer the research questions presented earlier. The sustainability reports were analyzed to assess the quality of data made available to stakeholders by the companies. The surveys and interviews provided a deeper understanding of the company's sustainability approach along with challenges faced during incorporation of sustainability initiatives and their public reporting. The ultimate aim of this research is also to investigate the relationship between reporting completeness and the social and environmental performance of semiconductor firms.

The initial source for selecting companies for this research was the annually published Silicon Valley SV 150 list by the San Jose Mercury News. The SV 150 list comprises the top 150 firms headquartered in Silicon Valley based on their annual revenues. The preliminary research highlighted that the expanse of the semiconductor manufacturing industry is not restricted to the Silicon Valley, and hence the scope of the study was broadened based on consultation with industry experts to include semiconductor manufacturers across the globe to gain a holistic understanding of sustainability performance and report completeness in this industry.

Qualitative methods such as interviews and surveys provided an overview of the key motivations behind publishing sustainability reports in the sample companies (RQ 1). Based on the study presented by Daub (2007), along with the findings of related research (Hughes et al., 2001; Krajnc and Glavic, 2005), a sustainability matrix was developed to assess the completeness of sustainability reporting by the sample semiconductor

manufacturers (RQ 2). The social and environmental best practices specific to the semiconductor manufacturing industry helped understand the advancement of sustainability performance in the sample firms (RQ 3). In addition, the mere adoption of sustainability best practices does not provide a complete understanding of the sustainability performance; hence, patterns and trends in normalized, absolute and historical data over 2010-2014 were assessed in the sample companies (RQ 3). The period from 2010-2014 was selected for analysis to avoid the period of global economic downturn. The following sections describe these research methods in greater detail.

Sample Selection

The Silicon Valley 150 list (SV 150) comprises of the top 150 companies headquartered in the Silicon Valley from sectors such as chip manufacturing, clean technologies, consumer electronics, etc. This list published annually laid the basis for selecting the sample companies. However, the global nature of the industry demanded the inclusion of companies across the world. After further review and discussions with the thesis committee, a sample of 20 companies was selected. The selected sample consisted of two types of companies: (1) fabs or integrated chip manufacturers (ICMs) that designed, manufactured, and sold their semiconductor products; and (2) foundries that specifically catered to the manufacturing demands of its customers (International Trade Administration, 2015). These two types of companies were selected as each had in-house chip manufacturing facilities and the social and environmental impacts of manufacturing were mainly of interest for this study. Although the companies were separated geographically, their impacts were almost alike because they manufactured

similar semiconductor products. The selected 20 companies were headquartered in different countries and the numerals in the brackets indicate the number of companies from each region: US (5), Japan (5), China (1), Taiwan (6), Europe (2), and S. Korea (1). Market cap of these companies ranged from $1.1 billion to $147.7 billion. In addition, the sample companies differed in size, where the number of employees varied from 1,269 to 107,600, and the net revenue ranged from $0.21 billion to $55.9 billion. These 20 companies constitute nearly 60-65% of the semiconductor manufacturing industry today based on the semiconductor sales (Statista, 2016). Appendix A represents strategic information about the selected sample companies.

RQ2 and RQ3, which dealt with sustainability performance and sustainability disclosure, were exclusively based on data extracted from the publicly available web-based sustainability reports of the sample companies. This study is restricted to only sustainability reports because (1) it is practically impossible for a researcher to study all documents related to sustainability published by a company, and the number of documents can be overwhelming, (2) all relevant documents may not be available publicly, (3) the information provided in other documents may not be accurate, and (4) the type of information provided in other documents depend on the audience of the document. Based on these conditions, the sample companies were selected such that they published sustainability reports online to aid easy data extraction for analysis.

The semiconductor industry experienced a significant sales decline during 2009, due to the global economic recession. The measures adopted by the companies indicated how these firms recouped after the meltdown in order to bounce back with the same vigor in

2010 to meet the increasing chip demands. The timeframe from 2010-2014 was therefore selected to avoid the period of economic slowdown. As data from 2010-2014 were important to this study, the sustainability reports from each company were selected such that data on social, environmental, and economic aspects was available for this timeframe. Thus, the number of reports studied from each company varied and about one to three reports per company were analyzed. The sustainability reports published by the company were downloaded from the company website and archived for later review. The names of the selected companies were coded to protect privacy and maintain confidentiality.

Further steps of data collection and analysis vary for the study about sustainability performance and report completeness. Content analysis of the sustainability reports facilitated the assessment of sustainability performance and report completeness. In addition, surveys provide an in-depth understanding about the factors that motivate sustainability reporting in the sample companies. Interviews with the sustainability managers provide deeper insights about the sustainability reporting process, sustainability best practices, as well as factors driving sustainability reporting in the firms. Figure 3 below outlines the structure of this research study.

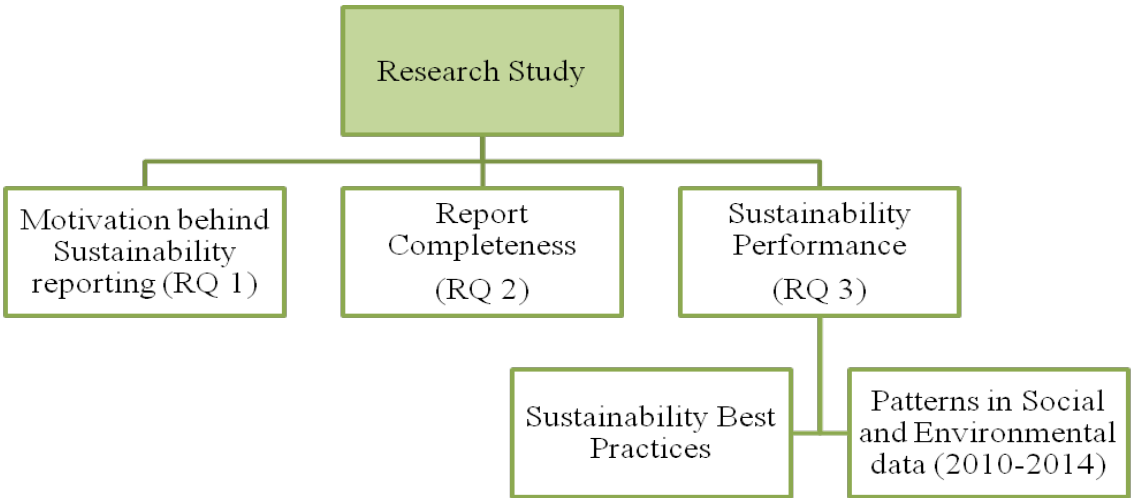

Figure 3. Outline of research study

Surveys and Interviews

Interviews and surveys were designed after detailed literature reviews of documents such as RobecoSAM Corporate Sustainability Assessment Questionnaire (2015), the United Nation's Questionnaire on Sustainable Development goals (2012) and UNEP's Frequently Asked Questions on Corporate Sustainability Reporting (2013). Further, the interview guide and survey document were finalized after discussion with the thesis committee. After the preparation of the interview guide (Appendix B) and survey document (Appendix C), an approval from the Institutional Review Board (IRB) at San Jose State University was sought before contacting the sustainability personnel from the sample companies for participation in interviews and surveys.

Surveys for assessing motivation behind sustainability reporting (RQ 1). Surveys were administered to gain a perspective about internal motivations behind publishing sustainability reports. The short survey was emailed to the CSR email of the 20 sample company or, in some cases, directly to the CSR Manager/responsible team. The

participants were asked to grade each of the motivating factors from 1 to 5, where 5 indicated “strongly agree” while 1 indicated “strongly disagree.” The survey also included a comments section where participants could add any input important to the study. Out of the 20 surveys emailed, 10 companies completed the surveys, resulting in an overall response rate of 50%. The analysis of the responses on the Likert scale was slightly modified for ease of understanding, such that grades 5-4 meant agreement, 3 meant neutrality and 2-1 meant disagreement. Although the response rate was satisfactory for this study, company policy prohibiting participation with such academic surveys deterred the participation rate of personnel. The survey results were analyzed using MS Excel, and the most common motivations behind adopting sustainability reporting were analyzed.

Interviews with sustainability managers. Interviewing is a powerful medium to understand managerial perspectives behind sustainability reporting (Ernst and Young, 2011). Similar to the study by Daub (2007), quantitative analysis to comprehend sustainability performance and disclosures were followed by interviews with sustainability managers of the sample semiconductor manufacturers to support the findings of quantitative studies. The same communication strategy adopted for surveys was replicated for interviews. The CSR emails of the 20 sample companies were contacted regularly to communicate with the responsible CSR personnel or team from each company. The introductory mailing outlined the study’s major purpose and research questions. Several follow-up emails were sent to ensure requests were at least addressed, if not agreed. Out of the 20 companies contacted for interviews, nine replied and five

agreed to participate in the interview. Thus, the response rate for the interviews was 25%. The companies that participated in the interviews were IT, TS, ST, NV, and UN.

The CSR emails of the companies were contacted to reach the managers responsible for the sustainability initiatives in the company. Usually, the email was communicated internally and the responsible manager directly contacted the researcher of this study. The participants were managers, executives and team members of the sustainability department at the sample semiconductor manufacturing companies. The only criterion used for selecting the participants for these semi-structured interviews was his/her familiarity with the corporate sustainability practices of his/her company (sample semiconductor manufacturer). Two strong reasons for selecting these personnel was their greater acquaintance with the company's sustainability practices and awareness about the challenges faced during data compilation and report preparation.

The estimated number of participants for the interviews was at least 10, but five companies agreed to participate. The semi-structured interviews were conducted via telephone, because some of the interview participants were located overseas. The semi-structured, in-depth interviews were 45-50 minutes long and were based on the interview guide developed for the study. The interview consisted of 14 open-ended questions about the participant's company. Every participant was told that participation in the interview was voluntary and that he or she could back out at any point.

The consent form (Appendix D) for participating with the interviews was emailed to the interviewees before the interview. The participants were asked to contact the researcher, in case they needed any clarification. The participants emailed back the

signed consent form prior to the interview. To ensure the participants agreed to participation with the interviews, they were once again asked about any specific concerns before the start of the interview. The interviews were audio recorded with the consent of the participant.

Audiotapes were transcribed into computer files using Microsoft Word software. During the interview transcription, each participant was assigned a unique code, which maintained his or her identity as confidential and discreet. After transcribing the data, the analysis of the transcripts was based on the grounded theory approach that involves searching for common themes across interviews. During publication, appropriate pseudonyms were used, such that no identifiable information was disclosed.

Content Analysis

Assessment of completeness in sustainability reporting (RQ 2). Completeness in the context of this study refers to data assessment with respect to clarity, historical trends, description, applicability, language, and presentation. The following segments describe the steps involved when assessing the completeness of sustainability reports of the sample companies.

Data collection. Initially, a content analysis of the selected sustainability report containing data from 2010-2014 for the sample semiconductor manufacturing companies was conducted (Asif et al., 2013; Al-Tuwaijri et al., 2004; Clarkson, 2008; Daub, 2007; Ingram and Frazier, 1980; Patten, 2002; Roca and Searcy, 2012). Since most companies followed GRI reporting guidelines, the GRI G4 and G3.1 guidelines were referred to ensure uniformity of the data analysis. Subsequently, descriptive and numerical data

from 2010-2014 on environmental, social, and economic parameters was recorded in MS Excel spreadsheets. In addition to the reports, the websites of the sample companies were referred to extract supporting qualitative and quantitative data about resource usage, emissions, and social aspects. Consequently, 20 spreadsheets were produced such that they were uniquely labeled and coded to maintain confidentiality of each company.

Data analysis. Daub (2007) developed a sustainability matrix based on GRI reporting guidelines for grading the "completeness" or "quality" of the data presented in the sustainability reports. The sustainability matrix developed by Daub (2007) was slightly modified to suit the selected industry and the purpose of the study and shall henceforth be referred to as 'modified sustainability matrix.' The modified sustainability matrix uses publicly available data and involves simple and understandable calculations (Docekalová and Kocmanová, 2015). Based on these criteria, the data for 33 parameters was collected, such that it covered environmental, economic, social, and other strategic information about the company. Each of the 33 parameters were graded from 0-3 based on factors, such as (1) presence or absence of parameter specific data, (2) coverage and description of the parameter, (3) presence of quantitative data, (4) representation of historical data, and (5) structure, layout, and language of the report (Daub, 2007; Lozano, 2012; Wiseman, 1982). The grading system was developed, such that disclosure of quantitative performance data was highly desirable. The detailed grading scheme is described in Table 3.

Table 3
Grading scheme for modified sustainability matrix

0 = Parameter not mentioned in sustainability report
1 = Information is partially reported
2 = Information is fully reported but lacks one relevant area/aspect
3 = Complete information with historical data and supporting graphics/ information

A higher score in this sustainability matrix was possible if the data represented in the report was cohesive and displayed good quantitative data. Daub (2007), in the original sustainability matrix, grouped the 33 parameters (Table 1) into four criteria, as presented in Table 4.

Table 4
Criteria for original sustainability matrix

Original Criteria		Number of parameters
A	Context and Coverage	**4**
B	Policies Management Systems and Stakeholder relations	**7**
C	Dimensions of Performance	**16**
	C1 Economic disclosure	*4*
	C2 Environmental disclosure	*5*
	C3 Social disclosure	*5*
	C4 Integrated disclosure	*2*
D	Transparency and general view	**6**
	Total parameters	**33**

The original calculations conducted by Daub (2007) were modified for this study to emphasize environmental and social disclosures, because these were the most understudied criteria in the past literature about sustainability reporting disclosures. Since the primary objective of every company is financial performance and profits, it leaves no reason to doubt that annual reports publish this information by and large. Environmental and social disclosures are necessary to understand the impacts of semiconductor industries during production, consumer use, and end of lifecycle. Based

on these observations, the original criteria represented in Table 3 were adjusted, such that the modified sustainability matrix assigned **environmental** (criteria C2) and **social** disclosures (criteria C3) 33.3 points each, and the remaining 33.4 points were covered by **overall strategic** disclosures**,** which comprise (1) context and coverage (Criteria A), (2) policy management systems and stakeholder relations (Criteria B), (3) economic performance (Criteria C1), and (4) transparency and general view (Criteria D). In addition, integrated disclosure criteria (Criteria C4) that consist of two sub-criteria were split such that one sub-criterion was added in environmental disclosure (Criteria C2) and the other was combined into economic disclosure criteria (Criteria C1). Table 5 represents the new categories of the modified sustainability matrix.

Table 5
Modified weight and criteria based on modified sustainability matrix

	Modified Categories	No. of criteria	Max. points per criteria	Max. point	Weight (points)
1.	**Overall strategic disclosures** Context and Coverage (Criteria A) Policies Management Systems and stakeholder relations (Criteria B) Economic disclosure (Criteria C1)* Transparency and general view (Criteria D)	22	3	66	33.4
2.	**Environmental disclosures** (Criteria C2)*	6	3	18	33.3
3.	**Social disclosures** (Criteria C3)	5	3	15	33.3
	Total	33	3	99	100

**Note*. Two sub-criterions in the integrated disclosure criteria (C4) are split, such that one is added to economic disclosures and other is incorporated in environmental disclosures.

Calculations for each of the 20 sample companies were conducted based on the modified sustainability matrix given (Table 5). The points received for each category were normalized with the weight of that category to obtain a percentile value of the total

disclosures. Initially, the maximum points possible for any company were 99, because each of the 33 criteria was graded from 0-3. But the normalization of data (Table 6) allowed each company to receive a maximum 100 points in sustainability disclosures. Table 6 describes the calculations for normalizing the disclosures values to assess the percentage values of overall strategic, environmental, social and total disclosures in the sample companies.

Table 6
Calculations for modified sustainability matrix

No	Categorical disclosures	Score received (I)	Max. points (II)	I/ II (III)	Point weight assigned (IV)	Point score received (V)	Max score possible
1	Overall strategic	X	66	X/ 66	33.4	III * IV	33.4
2	Environmental	Y	18	Y/ 18	33.3	III * IV	33.3
3	Social	Z	15	Z/ 15	33.3	III * IV	33.3
	Total score received (points)					Sum of above 3	100

Results of the sample companies based on the above calculations were tabulated for each category of disclosure (overall strategic, environmental, social, and total). The scores received for each category were sorted in descending order. Based on this assortment, two groups were differentiated such that each group displayed distinct characteristics about data disclosures. The group of companies that disclosed in-depth information on sustainability aspects of the organization comprised the top-disclosure group, while the group that published reports that significantly less data formed bottom-disclosure group. The two groups each contained four to six companies. Similarly, companies were also sorted into two groups for social, environmental, overall strategic disclosures and total sustainability disclosures such that companies in each group

exhibited similar disclosure characteristics in each category. Most researchers, other than Morhardt (2010), have exclusively analyzed the unique features, motivations, and initiatives of the top companies during the research about disclosures and performance. This study, on the contrary, investigates disclosure trends of the bottom scorers along with the top scorers. Such a novel approach provides a better understanding of the maturity of sustainability reporting practices in the two polar groups of companies.

Assessment of sustainability performance (RQ 3). The analysis of sustainability performance (RQ 2) involves two methodologies. The advancement of the sustainability in a company is based on the number of sustainability best practices adopted in-house and in the supply chain. Further, sustainability performance (RQ 2) is investigated by analyzing the underlying trends in the normalized, absolute, and historical data for environmental and social parameters extracted from the sustainability reports. Descriptive trends analysis is conducted for ecological data and majority of the social data. The next sub-sections describe the steps involved for the exhaustive study assessing the sustainability performance of the sample companies.

Data collection. Initially, a content analysis was conducted to extract descriptive and numerical data from the sustainability reports of the 20 sample companies. Out of the 28 sustainability best practices specific to the semiconductor manufacturing sector, the number of best practices in each company was tabulated. Similarly, the normalized, absolute and historical data for social and environmental parameters was collected from the sustainability reports for 2010-2014. Appendix E presents an example of the data collection framework used to extract data on the different sustainability parameters for

each of the 20 sample companies. The data collection methodology was the same as mentioned in the above section on reporting completeness.

Data analysis. The literature review indicated that several researchers have investigated sustainability performance in different industries based on the waste production or pollution. Arbogast and Thornton (2012) mention that sustainability performance of organizations can also be measured through a balance of leading indicators and lagging indicators. Lagging indicators measure results (e.g., reduction of waste produced), while leading indicators provide an overview of the internal practices adopted to improve future performance, e.g., conducting LCA (Arbogast and Thornton, 2012). In this context, the leading indicators are the sustainability best practices while the trends in social and environmental data over 2010-2014 are the lagging indicators. Toxicity in water, global warming, resource depletion, and water stress are the key environmental concerns of the semiconductor industry (Villard et al., 2015). Beyond these key areas of concern, the literature review and report analysis identified a broader set of 28 environmental and social best practices, which are indicators of the company's sustainability performance (Table 2). Participation in the carbon disclosure project (CDP), conducting LCA, performing carbon footprints and water footprints, elimination of ozone depleting substances (ODS), and reuse of ultra pure water (UPW) are some of the prominent environmental best practices in this industry. Similarly, some best practices in the social context are providing fair wages to employees, ensuring zero OSHA accidents, using conflict-free minerals, and ensuring diversity and equality at work.

Appropriate sustainability strategies and practices ensure a win-win-win situation for the company, environment, and society in the long run. Sustainability strategy differs from company to company. The advancement in sustainability was analyzed based on the number of best practices adopted by each company. The greater the number of best practices in a company, the more proactive it was with respect to sustainability. The number of best practices adopted in each company was tabulated such that green indicated that the practice was adopted, and white indicated that the practice was absent (Appendix F). Based on the adoption of these 28 best practices, the companies were divided into two distinct groups: group 1 and group 2. The criterion for choosing these two groups was that group 1 contains companies, which incorporated the most number of best practices, while group 2 constitutes companies with a considerably smaller number of practices. In addition, the companies in each of the two groups had distinct characteristics specific to the genre of the best practice adopted, which made them unique to the specific groups. The best practices adopted by the two groups were analyzed in greater detail to understand the sustainability approach of each group.

The second part of the sustainability performance analysis involves understanding the patterns in the social and environmental data during the years 2010 to 2014. Initial data review highlighted that use of normalized data would be useful for this sample. The sample constitutes companies that produce similar products but differ in size. Since the companies were not size-consistent, it was obvious that their resource use, emissions, and overall impact on society and environment varied. As a result, the comparison of companies based entirely on absolute values of parameters was avoided, because small-

sized companies may have less production and hence fewer emissions. The converse would be true for large sized companies. Thus, use of normalized data ensures a more fair comparison of the resource use and impacts in the sample. In addition to normalized data, absolute data proved to be a valuable indicator. Several past and present studies have extensively analyzed economic trends in these companies; therefore this study specifically investigated only the trends in social and environmental data. As a result, the sustainability performance of companies was judged on seven categories - six environmental and one social as represented in Table 7.

Table 7
Criteria for assessing sustainability performance through trend analysis

No	Category	Sub-category	Unit of analysis
1	Energy use	Electricity use	kWh
		Natural gas usage	Ton of Energy (TOE)
2	Waste generation	Total solid waste production	g, kg, or ton
		Hazardous waste production	g, kg, or ton
		Non- hazardous waste production	g, kg, or ton
3	Water consumption	Total Water consumption	m^3 or liter
		Wastewater production	m^3 or liter
4	Greenhouse gas (GHG) emissions	Total GHG emissions	t-CO2e or kg-CO2e
		Scope 1 GHG emissions	t-CO2e or kg-CO2e
		Scope 2 GHG emissions	t-CO2e or kg-CO2e
5	Other air emissions	Volatile Organic Compound (VOC) emissions	g or kg
		Nitrogen oxides (NOx)	g
6	Ecological responsibility	NA	NA

No	Category	Sub-category	Unit of analysis
7	Social impact	Investments, donations, and activities undertaken for the community and social well-being	NA

Source: Sustainability reports of the sample companies

The environmental data was either normalized with respect to the number of units produced (i.e., per chip, per 8" layer or per wafer) or with respect to net revenue (i.e., per million dollars). This normalized data was readily available in the sustainability reports analyzed. Some of the normalized data was available with respect to normalized production index where the resource use and emission values for a certain year were considered as the baseline. For example 2010 = 100 meant that the values in the year 2010 were considered the baseline for future reductions. Since there is no standardized format for calculation and reporting the normalized resource use and emissions in the reports, representing the historical values from 2010-2014 on the same graph was a formidable challenge. The graphs presented in this study contain data for two to four companies that followed the same trend. Plotting data for all the companies following the same pattern on a single graph was impossible due to the high variations in the units. In some cases, the increase or decrease represented in the graphs could be visually undetectable or even negligible, but even a small deviation in the emissions and resource use from 2010-2014 was important for this study.

Some researchers claim that past trends may not provide an accurate prediction of the company's future performance (IT CSR report, 2015). However, these trends definitely portray the effectiveness of past sustainability practices and technologies. Line graphs

were plotted to understand the trends of the normalized data for the five environmental categories listed in Table 7. The normalized data for each environmental category (i.e., energy use, waste generation, water consumption, greenhouse gas (GHG) emissions, and other air emissions) followed three types of trends when five years of data from 2010-2014 was analyzed. Each of the trends is discussed below.

1. Decrease - During the five-year period, if normalized values are higher during the initial years and decrease gradually or significantly year-to-year, then this trend is described as decrease.
2. Increase - Over five years (2010-2014), the normalized values of the resource use or emissions increase gradually. This trend is known as an increase in this study.
3. Mixed - When the five-year normalized data shows no distinct increase or decrease, it is denoted as a mixed trend.

Qualitative methods such as interviews and surveys help in understanding the internal motivation behind publishing sustainability reports for this study. The interviews also provide deeper insights about the sustainability approach and initiatives that are usually not evident from the sustainability reports. The next section discusses methods for analyzing the report completeness and sustainability performance.

Relationship between Sustainability Performance and Report Completeness

Based on previous sections, sustainability performance was investigated based on adoption of sustainability best practices and assessment of environmental and social data trends. Similarly, the completeness of sustainability disclosures was assessed based on a modified sustainability matrix developed for this study. Most of the studies in the past

have investigated the relationship between CSR adoption and financial performance (Bert, 2008; Lu, Wang and Lee, 2013; McWilliams and Siegel, 2001). Similarly, the relationship between environmental performance and disclosures has been studied extensively, but there is no consistency in the findings (Al-Tuwaijri et al., 2004; Bewley and Li, 2000; Clarkson et al., 2008; Cowan and Deegan, 2010; Freedman and Wasley, 1990; Herbohn, Walker, and Loo, 2014; Ingram and Frazier, 1980; Patten, 2002; Wiseman, 1982). As very few studies have investigated the relationship between sustainability performance and report completeness, this research examines this association.

Limitations of the Research Methodology

With the expanse of the semiconductor manufacturing industry as a global enterprise, adequate care was taken to include companies from around the world. Despite this fact, the number of companies selected from each country was not equal in the sample. Such an unequal mix of the sample companies restricts the correlation of the results with geographical regions. Secondly, the modified sustainability matrix used in the study is also subject to some limitation in its applicability to multi-sectoral studies. Thus, the use of the modified sustainability matrix may yield varying results for companies from different sectors and across geographical regions. Thirdly, the administered surveys provide a greater understanding of the company's philosophy behind the adoption of sustainability reporting. Since the sample size of the survey population is small, the results of the survey are fairly generalizable to the entire semiconductor industry. In addition, the analysis of sustainability performance, with respect to the adoption of best

practices, is a novel concept and the selected best practices are applicable only to the industry under study. Application of the same methodology to other sectors will require a separate literature study to identify best practices specific to that industry. Furthermore, data from the sustainability reports is collected using manual techniques and hence the exhibited trends were based on only five years of available data. Even though five years is a reasonable time span for this analysis, the trends may differ if data over a longer time period is analyzed. Lastly, sufficient caution is maintained by discussing grading and content analysis with the thesis committee members to ensure no bias exists in the analysis.

Results and Analysis: Completeness of Sustainability Reporting

This chapter acknowledges the need to answer the question, "How well do companies disclose information in their sustainability reports?" The reports published by companies are powerful tools that ensure a constant dialogue between the company and its stakeholders (Gray et al., 1995). Sustainability reports should paint a transparent and true picture about the company's outlook about environmental and social matters. The former portion of this chapter lays a background for this study about sustainability reporting and investigates the factors that motivate sustainability reporting by the sample companies. The latter section discusses the findings about the "completeness" of sustainability reporting.

Sustainability Reporting Basics

The sustainability reports published by five sample companies were multilingual and catered to different audiences across the world. Ten out of 20 sample companies mentioned that the reports were published to communicate the company's sustainability initiatives with stakeholders such as employees, investors, shareholders, academia, NGOs, government officials, suppliers, and contractors. For example, company SH in its sustainability report mentions that it publishes reports "to share the vision, strategies, and activities involving the sustainability management that the company pursues with its stakeholders and to ensure that their feedback and opinions are incorporated into corporate policies and decision-making" (SH sustainability report, 2014). In a typical semiconductor manufacturing firm, the entire process of publishing sustainability reports takes about five to six months and requires a considerable workforce to extract data

across departments and geographic locations of the company (Corporate Responsibility Manager at ST, personal communication, August 24, 2015). The CSR/sustainability department works in collaboration with other departments to draft sustainability reports, and the reports are generally published only after seeking approval from top management (Corporate Responsibility Manager at ST, personal communication, August 24, 2015; HR Manager at UN, personal communication, October 9, 2015).

Based on respondent feedback and literature review, adoption of GRI sustainability reporting guidelines and third party assurance of reported data are the two most valued sustainability best practices that ensure transparency and add credibility to the sustainability data. The sampled companies were all cognizant of the GRI guidelines. The adoption rate of the GRI reporting guidelines was high among the sample companies (16 out of 20). In addition, other guidelines published by International Organization for Standardization (ISO), AccountAbility (AA), and Ministry of Environment (Japan) were also adopted by some companies. On the contrary, the practice of seeking third party assurance of sustainability data was still an emerging trend in the sample. Only eight out of 20 (i.e., 40%) sample companies presented third party-certified data in the sustainability reports. The quotes extracted from the interviews with the sustainability officials of sample companies shed light on this trend.

For example, the CSR Communications Manager at IT (personal communication, August 14, 2015) mentioned the following thought.

> I don't think it (third party assurance of data) is necessary. It definitely gives the report a lot of credibility. If you compare it to the financial reporting process, you are required to have an auditor look at your financial data as it does add

> credibility. (CSR Communications Manager at IT, personal communication, August 14, 2015)

Similarly, the Director of Sustainability Stakeholder Relations at TS (personal communication, August 18, 2015) expressed the following opinion.

> I wouldn't say it [third party assurance of data] is important right now. Companies should be doing their due diligence to make sure anything that they put out publicly is accurate and auditable. The three factors that keep us away from seeking third-party assurance to our sustainability report are one, no set way of auditing; two, enormous costs and three, rigorous internal audit standards (Director, Sustainability Stakeholder Relations at TS, personal communication, August 18, 2015).

In contrast, the Corporate Responsibility Manager at ST (personal communication, August 24, 2015) felt differently.

> Yes, it (third party assurance of data) is important as it creates credibility. For assurance, we do a full audit which is quite heavy. We decided not to do it in one year and our scoring by analysts dropped in comparison to when a 3rd party verification was done. [When you do it on your own], you can write anything and no one knows if it is correct or not. There is no way to find what is actually happening in the company. Therefore, 3rd party assurance adds credibility (Corporate Responsibility Manager at ST, personal communication, August 24, 2015)

These quotes clarify that external assurance adds credibility to the data, but the lack of a standardized framework is the major hurdle to its adoption. In the sample, four out of five top-scoring companies in the total disclosure category certified the environmental data through a third party agency, while only one out of five companies from the bottom scorers integrated this practice into their sustainability reports. A possible explanation for this trend in seeking third party assurance among companies with good disclosure practices could be to achieve competitive advantage. Figure 4 and Figure 5 illustrate the

adoption rate of GRI guidelines and third party assurance among the 20 sample companies.

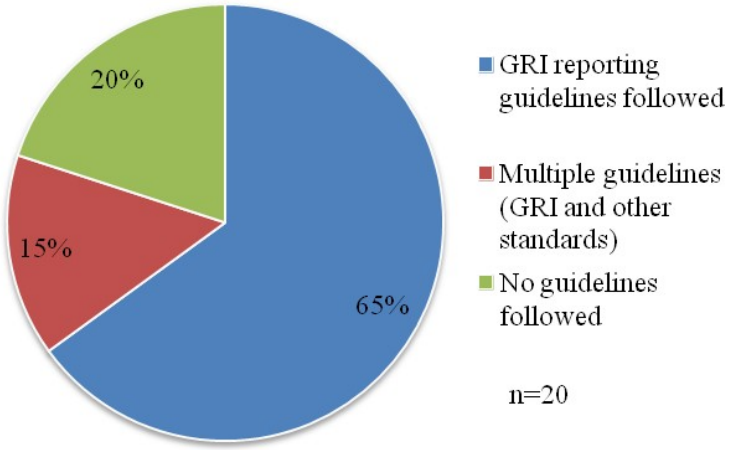

Figure 4. Sustainability reporting guidelines followed in the sample. (Based on analysis of sustainability reports of sample companies)

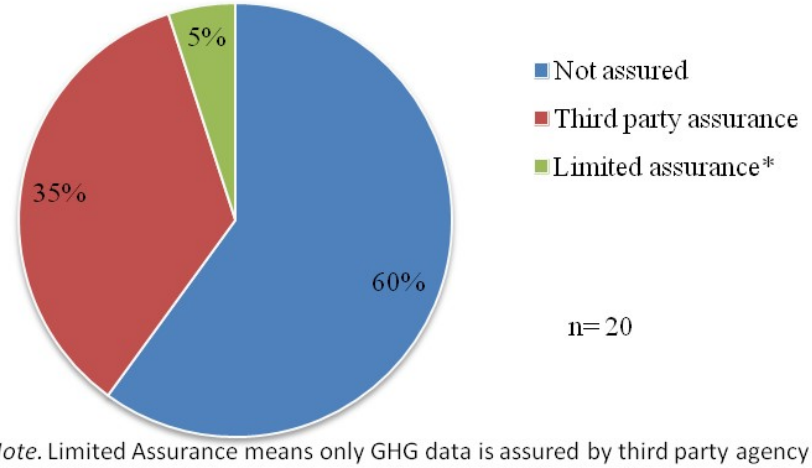

Figure 5. Overview of external assurance to sustainability reports in the sample. (Based on analysis of sustainability reports of sample companies)

The next section assesses the motivating factors behind publishing sustainability reports in the sample companies.

Motivation behind Sustainability Reporting

Surveys were administered to understand the factors that motivated sustainability reporting in the sample companies. The survey document (Appendix C) was emailed to all 20 sample companies and ten companies returned the completed surveys by email. The ten companies that participated in the survey and shared information in this context were FS, IT, AS, NV, SC, ST, TS, TK, UN, and UC.

Based on the survey results, all ten respondents strongly agreed that ethical responsibility and concern for the environment and society were the key motivations for publicly reporting about sustainability. Additionally, eight out of ten participants strongly agreed that publishing information about sustainability programs positively affected the shareholder value of the company. The literature review highlights that companies report about sustainability as a way to gain a competitive edge (BCCCC and Ernst and Young, 2013; Lu, Wang, and Lee, 2013) and the majority of the survey participants (8 out of 10) supported this assertion. Seventy percent of the respondents considered building a green corporate image as a motivating factor for sustainability reporting. Nonetheless, all the survey participants consented that sustainability reports facilitated a dialogue between stakeholders and the company.

This section described the motivation behind engaging with sustainability reporting for the surveyed sample semiconductor manufacturing companies. Continuing with the same theme, the next section investigates the completeness of reporting. The three disclosures categories, environmental, social, and overall strategic, assessed using the

modified sustainability matrix provide a deeper understanding about the individual components of sustainability (i.e., environmental, social, economic, and governance).

Completeness of Sustainability Reporting

The completeness of social, environmental, and economic disclosures of the sustainability reports by the 20 sample companies was investigated using the methodology adopted by Daub (2007). A total of 40 sustainability reports were studied from the 20 sample companies listed in Appendix A. The modified version of the sustainability matrix developed by Daub (2007) was applied to calculate the percentage of disclosures by the 20 sample companies. This modified version is henceforth referred to as the "modified sustainability matrix." Table 8 describes the calculation conducted for sample company AD.

Table 8
Example of score calculations for sample company AD

Category	Score received (I)	Max points (II)	I/ II	Point weight assigned	Point score received	Max score possible
Overall strategic disclosure	50.0	66.0	0.8	33.4	25.3	33.4
Environmental disclosure	10.0	18. 0	0.6	33.3	18.5	33.3
Social disclosure	12.0	15.0	0.8	33.3	26.7	33.3
Score received (%)					70.5	100

Similar calculations as shown in Table 8 were conducted for the other 19 companies. Table 9 tabulates the results of this analysis in descending order based on the total disclosures scores received by the 20 sample companies. Each company could score a maximum of 33.3 points in each of the environmental and social disclosures categories and 33.4 points in the overall strategic disclosure category. Thus, the maximum total

disclosure score any sample company can receive is 100 points. Based on these calculations in Table 9, the maximum total scores (96.6) for this sample was nearly double the minimum total score (48.4) received.

Table 9
Total scores based on modified sustainability matrix

Company name	Overall strategic disclosure	Environmental disclosure	Social disclosure	Total Score
1. UC	31.8	31.5	33.3	96.6
2. SH	31.3	31.5	31.1	93.9
3. ST	31.8	27.8	33.3	92.9
4. IT	31.3	27.8	33.3	92.4
5. TS	26.8	33.3	31.1	91.2
6. NN	27.8	27.8	31.1	86.7
7. UN	28.3	27.8	28.9	85.0
8. TC	27.3	29.6	26.7	83.6
9. NV	24.8	27.8	28.9	81.4
10. TK	23.7	27.8	24.4	75.9
11. RN	24.8	25.9	24.4	75.1
12. SO	19.2	27.8	24.4	71.4
13. AD	25.3	18.5	26.7	70.4
14. MR	23.2	25.9	20.0	69.2
15. IN	24.3	18.5	24.4	67.2
16. AS	27.8	16.7	22.2	66.7
17. RO	26.8	24.1	15.6	66.4
18. SC	22.2	16.7	22.2	61.1
19. GF	20.7	20.4	11.1	52.2
20. FS	17.7	13.0	17.8	48.4
Max. score	**33.4**	**33.3**	**33.3**	**100**
Average score	**25.84**	**25.0**	**25.6**	**76.4**

A wide disparity of total scores indicates a need to study the disclosure practices of the two distinct groups of companies, which are top scorers and bottom scorers based on completeness of information furnished in their sustainability reports. For the sake of clarity, these two distinct groups of companies are differentiated based on the scores received for each type of disclosure category (environmental, social, and overall strategic) and total disclosures. The two groups for environmental and overall strategic

disclosure categories are divided, such that companies with a score below 22 comprised the low disclosure group and scores above 28 constituted the high-disclosure group. Similarly, in the social disclosure category, scores above 31 and below 20 were grouped together and labeled as the high disclosure and low disclosure group, respectively. Lastly, the total disclosures for the 20 sample companies were distinguished into two groups, such that scores above 91 and below 67 constituted the high disclosure and low disclosure group, respectively. The number of companies in each group ranges from four to six. Table 10 provides an overview of the two groups of companies for each disclosure category along with their scores.

Table 10
Top and bottom disclosure groups based on modified sustainability matrix

Disclosure category	Top scorers in disclosure (points received)	Bottom scorers in disclosure (points received)
Environmental	TC (29.6)	FS (13.0)
	SH (31.5)	SC (16.7)
	UC (31.5)	AS (16.7)
	TS (33.3)	IN (18.5)
		AD (18.5)
		GF (20.4)
Social	NN (31.1)	GF (11.1)
	SH (31.1)	RO (15.6)
	TS (31.1)	FS (17.8)
	IT (33.3)	MR (20.0)
	ST (33.3)	
	UC (33.3)	
Overall strategic	UC (31.8)	FS (17.7)
	ST (31.8)	SO (19.2)
	IT (31.3)	GF (20.7)
	SH (31.3)	SC (22.2)
	UN (28.3)	
Total	TS (91.2)	FS (48.4)
	IT (92.4)	GF (52.2)
	ST (92.9)	SC (61.1)
	SH (93.9)	RO (66.4)
	UC (96.6)	AS (66.7)

Note. Values in the bracket indicate the disclosure score received by the company

Further, the findings about completeness of sustainability reporting are divided into four sub-sections: environmental disclosures, social disclosures, overall strategic disclosures, and total disclosures. The final section discusses the relationship between completeness of sustainability reports and company size. In addition, the relationship between sustainability performance and completeness of sustainability reporting is also examined.

Environmental disclosures. Out of 33.3 points, the sample companies scored as low as 13.0 and as high as 33.3 in the environmental disclosures category. Similarly, the average scores in this disclosure category were 25 out of 33.3. The four top scorers and six bottom scorers from the sample followed distinct patterns, which made them unique as a group. Table 11 illustrates the common characteristics, specifically in environmental disclosures, present among the top and bottom disclosure group in the sample.

Table 11
Practices in top scorers and bottom scorers in the environmental disclosure category

No.	Practices	Characteristics of top scorers	Characteristics of bottom scorers
1.	No. of years into sustainability reporting	At least 8-9 years	1-6 years
2.	Historical environmental data in reports	2-5 years	2-5 years
3.	Number of environmental parameters addressed	Several aspects addressed simultaneously	Selected important aspects only

The grading scheme for environmental disclosure can be explained through the example of 'environmental pollution by emissions to air' where, if the company described 'GHG reductions is our priority for the year 2014,' then the company received 1 point. If no information on this aspect was published, then the company obtained zero points for this aspect. A company received two points if the report described information such as: 'A 5% reduction in Scope 1 GHG emissions is planned to be achieved by 2020 with 2010 emissions as the baseline. Projects such as retrofit of manufacturing equipments, exploring use of chemicals with lower global warming potential (GWP) and phasing out ozone depleting substances have been incorporated in 2015.' A company which provided complete information and received 3 points about this aspect provided historical quantitative data for two to five years about the scope 2 GHG emissions along

with the information provided previously. Most of the parameters were clearly described and could be easily distinguished on a scale of 0 to 3. In certain cases when the data determination was subjective, consultation with field experts assisted in consistent and fair assessment.

The four companies that comprised the top disclosure group in the environmental category were adept with the practice of sustainability reporting, as they published these reports for the last 8-9 years. In addition, the four top scorers in the environmental category addressed all the three aspects of sustainability simultaneously in the sustainability reports which was a unique feature of this group.

In addition, normalization of environmental data, with respect to unit production, was more common in the reports of all the 20 sample companies, as compared to normalization with respect to net revenue. The top scorers in this category presented normalized data per product manufactured for environmental parameters such as total GHG emissions, scope 1 emissions, scope 2 emissions, natural gas usage, electricity consumption, energy usage, water consumption, NOx emissions, SOx emissions, and waste disposal; whereas the bottom scorers disclosed normalized data on selective parameters. Usually, historical data trends about GHG, water, waste, energy, and other air emissions allow easy interpretation of the company's past and present environmental strategies and initiatives. In addition, the companies in the top-scoring and bottom-scoring group in this disclosure category went the extra mile to disclose two to five years' worth of historical quantitative data that provided a better explanation of in-house processes to stakeholders.

As discussed in chapter 4, disclosure of information about environmental fines and violations is a sustainability best practice which increases transparency. Stakeholders are most likely to believe published information on negative trends such as fines as compared to positive disclosures (BCCCC and EY, 2013). Data on monetary fines and violations was published by all four top scorers while only two out of the six bottom scorers reported this aspect. Consequently, the top scorers in the environmental disclosure category tended to report on fines and violations more frequently than the bottom scorers in the sample. A further investigation on this topic with a larger data set shall provide a better understanding of the correlation between the two aspects. All the sample company reports elaborated about environmental accounting and cost savings from the different water and energy-related projects.

Similarly, the adoption of projects on reducing energy use, waste production, and water consumption are also some sustainability best practices as noted in chapter 4 of this report. The six bottom-scoring companies from the sample described these projects very briefly, whereas the top scorers provided a complete picture of the company's efforts to tackle environmental impacts by providing in-depth descriptions. A possible explanation for the minimal information published in the sustainability reports of some sample companies could be the proprietary nature of the processes that might prohibit firms from publishing some key facts (GF CSR report, 2013). In addition, limited resources and inexperience in data collection techniques could be other factors affecting data disclosure quality among the two groups. Lastly, the sustainability reports of companies with

environmental disclosure scores intermediate between the top-scoring and the bottom-scoring group had no distinct common features.

Social disclosures. According to the World Semiconductor Council, semiconductor manufacturers across the world began investing in social initiatives after 2008, when it was understood that stakeholders were interested in interacting with the company (World Semiconductor Council, 2010). The interviews and sustainability report analysis conducted for this investigation revealed that the company sustainability reports had two types of audiences: (1) internal stakeholders such as employees, suppliers, customers, partners, shareholders, and investors and (2) external stakeholders such as academia, NGOs, government agencies, students, and media. The previous chapter shed light on information about human rights policies and conflict-free mineral policies among the sample companies. Information about fair and non-discriminatory wages for all workers was published by nearly 16 out of 20 sample companies. In addition, Environmental Health and Safety (EHS) data, such as OSHA severity rates and incidence frequency rates were published by all the 20 sample companies due to the presence of strict in-house EHS policies.

Table 10 displays the top-and bottom-scoring group in the social disclosures category, which consists of six and four companies, respectively. The significant disparity in the scores for the social category (11.1 to 33.3) indicates the developing nature of these types of disclosures. This disparity in scores is supported by the findings of Gutherie and Parker (1989), who found that, although some companies published data about employee welfare as early as the mid-1880s; the modern day practice of social reporting is still new

and emerging. Table 12 demonstrates the different disclosure patterns observed among the top and bottom scorers in the social disclosure category.

Table 12
Practices in top scorers and bottom scorers in the social disclosure category

No.	Social practices	Characteristics of top scorers	Characteristics of bottom scorers
1.	Description of activities	Detailed	Very brief
2.	Idea of describing social involvement	Mainly descriptions along with appropriate graphics	Photographs and graphics of employee volunteering
3.	Emphasis of social disclosures	STEM education, scholarships, employee training seminars, and girl child education	employee volunteering and charity donations
4.	Presence of historical data	Yes	No

In general, the grading scheme from 0-3 adopted to score the social disclosures can be explained with the example of "health and safety" related information. A company received one point if it described information such as, 'We have an EHS policy and EHS department that ensures that there are zero work related accidents and casualties.' A company received two points if it mentioned information like 'routine heath checkups and presence of an on-site medical professional at each of our sites makes our EHS program successful. Our in-house OSHA severity rate is consistently lower than the national average for the past 7 years. Our company conducts annual health and safety related trainings for our fab employees.' In addition to this information, if the company provided two to five years of historical data on its OSHA severity rate and incidence rate, then this elaborate and complete information on this topic received three points. Absence of any information on health and safety related topics resulted into zero points.

Sustainability reports of the four bottom scorers represent the developing nature of social disclosures in the sample. Brief descriptions of social activities and pages with pictures and graphics of employee volunteering are the key features of the sustainability reports of the bottom scorers in the social disclosure category. The bottom scorers in social disclosures usually invested in STEM education and scholarships, but the sustainability reports did not provide a detailed overview of these efforts. In contrast, the sustainability reports of top scorers published historical data about a variety of social investments, such as STEM education, scholarships, employee training seminars, and education programs for girls. A promising trend in the reports of top scorers was the presence of extensive data about employee safety and health programs, together with human rights audit results of supplier and contractor companies.

Overall strategic disclosures. The last category of this analysis is worth 33.4 out of 100 possible disclosure points. It consists of four criteria: (1) context and coverage of the report, (2) management policies and stakeholder relations, (3) economic disclosures, and (4) transparency and structure of the report (Table 4). Information about these four criteria is usually presented in the annual reports of every company. Based on this observation, the overall strategic disclosure category is the most described as compared to social and environmental disclosure category in all the sample sustainability reports. Due to the importance of environmental and social factors in sustainability reporting, the overall strategic disclosure category (33.4 points) is thus weighted less as compared to the combined point values of the environmental and social disclosures (66. 6 points). The

average percentage disclosures for this category were 25.8, and the scores ranged from 17.7- 31.8, on a scale of 33.4.

Table 10 displays the top and bottom-scoring group in the overall strategic disclosures category, which consists of five and four companies, respectively. The characteristics of each group are represented in Table 13.

Table 13
Practices in top scorers and bottom scorers in the overall strategic disclosure category

No.	Overall strategic practices	Characteristics of top scorers	Characteristics of bottom scorers
1.	Description of policies on economic, social and environment	Detailed	Sparse information
2.	Vision	Distinctly described	Not clear
3.	Stakeholders of the company	Well described	Well described
4.	Process of involving stakeholders in identification of sustainability priorities	Well described	Absent
5.	Risk management system description	Well defined along with graphics	Basic information
6.	Code of conduct	Detailed	Short description

The overall strategic disclosure covers a wide array of topics; some of which are economical well-being, governance, ethics, and stakeholder relations. The 0-3 grading scheme for grading this disclosure category can be explained with the example of data on 'Company profile and report profile.' If a company in its report describes information such as 'This report contains information from our manufacturing units located at China, Japan, and Taiwan. The report contains data for the fiscal year 2015,' then the company receives one point. A company received two points if it provided information such as 'the CSR report is intended to inform our stakeholders such as employees, suppliers, customers, community members about our internal code of conduct, operational management, social and environmental impacts and mitigation strategies. This is the

seventh CSR report published by the company. The report follows guidelines published by organizations such as the GRI (G3.1 and G4), ISO (26000:2010), and Ministry of Environment Japan (2012). In addition to the previous information, if the company describes that it uses data from 2010-2014 in the report compilation and links to previous reports, then it received three points for this information. It was a rare scenario when a company received zero points in any of the overall strategic disclosure sub-categories, as every company had been publishing this information in the annual reports for a very long time.

The description of policies related to economics, environmental, and social aspects helps the reader understand the philosophy of the company. The bottom scorers in the overall strategic disclosure category excluded these details; this could be to avoid redundancy. The "vision" of the company usually depicts the driving force behind the company's activities and decisions. The sustainability reports of some bottom-scoring companies did not describe this vision in detail. In addition, the reports of bottom scorers in this disclosure category published the different channels utilized to communicate with the stakeholders but failed to describe the actual process for involving them in the determining the sustainability key performance indicators. In contrast, the reports of the top scorers in this category described the channels of communication, along with survey results of stakeholder involvement which provided deeper insights of the process. Similarly, the code of conduct that directs the ethical and operational framework of the company was very briefly described in the reports of bottom-scoring companies, while

the top scorers provided links to appropriate websites or annual reports to access this information.

Total disclosures. The total disclosure score was calculated by combining the scores of the three disclosures categories: environmental, social, and overall strategic, described previously. Table 10 enlists the top and the bottom-scoring group in total disclosures and each group comprises of five companies. On an average, the total disclosure score for the 20 sample companies was 76.4 out of 100 points. This clearly indicates that the practice of sustainability reporting is well matured in the sample. The total disclosure score of the sustainability reports of the sample companies ranged from 48.4 to 96.6 out of 100. Such a wide discrepancy of the disclosure levels explains that companies are at different stages with regards to the adoption of sustainability practices and their reporting. The top scorers in total disclosure category may have published the most information to respond to the increasing concerns of stakeholders about operational impacts of the company. In addition, the two top scorers in the total disclosures- UC and SH have also disclosed good quality information in all the three categories (environmental, social, and overall strategic) of disclosures. Similarly, GF and FS were the two sample companies that had consistently low disclosure scores in all the three disclosure categories, whereas the other top and bottom scorers with respect to the total disclosure scores had appeared in the respective top and bottom groups in at least one of three disclosure categories.

The reports of the five top scorers with respect to total sustainability disclosures featured in-depth information on all aspects of their operations, such as environment, society, economics, governance, and ethics. These reports contained detailed qualitative

and quantitative data, along with historical trends that provided a better understanding of the past progress. Although historical trends do not guarantee future outcomes, present strategies and future planning definitely improve risk management (IT CSR report, 2014). The top scorers published historical data, which was supported by colorful, attractive graphics that facilitated easy understanding of data. A few reports also provided a navigation bar that assisted easy browsing through the contents.

In addition, the interviews conducted for this research highlighted that three out of the five top reporters (ST, TS, and IT) with respect to the total disclosures had a sustainability champion who guided sustainability strategies, project implementation, and actual reporting process for several years. Similarly, ST, a top-scoring company in total sustainability disclosure, also mentions that sustainability has guided its business principles for the past 20 years and is the key reason for the maturity of its sustainability practices and reporting (ST sustainability report, 2014).

As mentioned above, the bottom-scoring group with respect to the total sustainability score had low scores in at least one out of the three disclosure categories. Thus, companies are attempting to cover all three aspects of sustainability in their reports, but the comprehensiveness of information published for each aspect varies. The quality of sustainability reports is affected by challenges posed by underdeveloped data extraction systems, difficult data manipulations, workforce requirements, and cost constraints. Although bottom scorers published reports titled “sustainability reports,” these reports in actuality were similar to product brochures or magazines containing supplementary information on environmental and social initiatives of the company. Finally, the

sustainability report published by a top scoring company, ST, was data intense yet abridged (76 pages) and included all pertinent information requested by stakeholders. Thus, this report is an excellent example of a good quality sustainability data and could be used as a model report by other semiconductor manufacturing companies.

Results and Analysis: Sustainability Performance Based on Best Practices

This section illustrates the extent to which individual firms demonstrate CSR 'best practices,' as identified from the literature review. As highlighted in the literature, GHG emissions, electricity consumption, raw material usage, and chemical inputs are the four key environmental concerns in the semiconductor industry (ITU Symposium, 2010; Liu, Lin and Lewis, 2010; Villard, Lelah, Brissaud, 2015). The social impacts of semiconductor manufacturing have been extensively investigated, and the ill effects on human health have been associated with this industry for a very long time (Siegel, 1995).

Based on this limited set of information, it was understood that sharing knowledge about the social and environmental best practices adopted by individual semiconductor manufacturing companies would definitely prove to be a mutually beneficial practice for the industry consortium (ICT, 2010). Incorporating best practice can also boost a firm's performance (Reijers and Liman-Mansar, 2005). The research on sustainability practices in the semiconductor industry is still not as developed as other sectors (Villard et al., 2015). Table 2 enlists the 28 best practices identified specifically for the semiconductor manufacturing industry. Participation in the Carbon Disclosure Project (CDP), elimination of ozone depleting substances (ODS), acquiring green building certifications, and reuse of ultra pure water (UPW) are some examples of these environmental best practices. Similarly, some best practices that demonstrate a company's social responsibility are paying fair wages to employees, having zero OSHA incidents, instituting a conflict-free mineral policy, and promoting diversity and equality at the workplace.

Appendix F of this report provides an overview of how many of the 28 best practices were adopted by each sample company. These 28 best practices consist of sustainability indicators, product related design standards, and communication tools (Horisch, Johnson, and Schaltegger, 2015). Based on this tabulation (Appendix F), IT was the only company from the sample that adopted the maximum number of best practices (i.e., 23 out of the 28). On the contrary, SO and SC were the two sample companies that adopted the least number of best practices (i.e., 10 out of 28). This wide differentiation in the adoption of best practices indicates that the approach and maturity of sustainability management systems in companies vary. Further investigation of the sorted data highlights that the top five and bottom five companies from the list possessed similar characteristics and distinct patterns in the types of best practices adopted. Based on this observation, for the sake of identification, two distinct categories of companies were obtained such that the top five companies were titled group 1, while the bottom five companies constituted group 2.

Group 2 companies, with respect to adoption of best practices, were characterized by the presence of a sustainability strategy and dedicated CSR department, adoption of basic ISO certifications, conducting regular in-house audits, and the presence of a human rights and conflict minerals policy. In contrast, group 1 companies incorporated several state of the art practices, in addition to those adopted by developing companies. Some of the features that distinguished group 1 companies from group 2 companies were the adoption of advanced ISO certifications, measurement of carbon and water footprints, use of LCAs, and incorporation of water conservation projects. The other 10 companies from

the sample that did not fall under group 1 or group 2 possessed all the salient characteristics of group 2 companies, but no discernible pattern in the other practices was found. Table 14 synthesizes sustainability best practices in companies constituting group 1 and group 2 where green indicates that the practice was adopted while white represents that the practice was absent.

Table 14
List of best practices adopted by group 1 and group 2 companies

No	Best practices in sustainability	Name of company									
		IT	AD	UC	SH	IN	TK	NV	NN	SO	SC
1	Long term sustainability goals	■	■		■	■					
2	Sustainability strategy and department	■		■	■	■	■	■	■	■	■
3	Product compliance certification	■	■	■	■	■	■		■	■	
4	Risk management system	■		■	■	■		■		■	■
5	Environment Health and Safety policy and department	■	■	■	■	■	■	■	■	■	
6	Energy efficiency projects	■			■	■					■
7	Green building certification	■	■	■							■
8	Human rights policy	■	■	■	■	■		■	■	■	
9	Conflict minerals policy	■	■	■	■	■	■			■	■
10	Employee and customer survey		■	■	■		■		■	■	
11	Materiality analysis for identification of sustainability KPI		■	■	■	■		■	■		
12	Climate change and elimination of ODS	■	■	■		■					
13	Life cycle assessment	■	■	■	■		■				
14	Fair wages	■	■	■	■	■			■		■
15	CDP disclosure and carbon-water footprint	■	■	■	■			■	■		
16	Reusable packaging	■	■								
17	Reduction and reuse of ultra pure water	■				■					
18	Supplier responsibility	■	■	■	■	■		■			■
19	Green transportation	■	■								
20	Waste reduction projects		■		■	■	■	■	■		
21	Third party assurance of sustainability report		■	■		■					
22	Diversity and inclusion	■				■					
23	Water conservation projects	■	■	■	■	■					■
24	Fines and violations	■		■	■		■	■			
25	Normal working hours		■								
26	Sustainability benchmark certificates	■	■	■	■	■	■	■	■	■	■
27	Facility audits	■		■	■	■	■	■		■	
28	Sustainability reporting	■	■	■	■	■					
	Total number of practices adopted	23	21	20	20	20	12	12	11	10	10
Notes. Green block represents that the best practice was adopted in the company while white block indicates it was absent											

As observed in Table 14, the number of green blocks is more concentrated in the first five columns as compared to the latter five columns. This indicates that the first five companies adopted many best practices as compared to the latter five. Table 15 outlines the companies that constitute group 1 and group 2 as observed from the Table 14.

Table 15
Companies based on adoption of best practices

No	Group 1	Group 2
1.	SH	SO
2.	IT	SC
3.	AD	NN
4.	IN	NV
5.	UC	TK

The following sections further illustrate the main differences between group 1 and group 2 companies, as observed from the analysis of the sustainability reports of the sample companies. For sake of understanding, the 28 best practices are grouped into six broad sections which are organizational structure for sustainability, manufacturing related sustainability indicators, ecological responsibility, supply chain management, social responsibility, and transparency and benchmarking.

Organizational Structure for Sustainability

Sustainability strategy and CSR department. Sustainability strategy formulation and its implementation through programs are the two vital phases of introducing sustainability into the company's management system (Engert and Baumgartner, 2015). Presence of a sustainability strategy is a fair indication about the company's willingness to adopt sustainability initiatives (Engert and Baumgartner, 2015). In the sample, 17 out of the 20 companies had a distinct sustainability strategy, which is usually the starting

point for incorporating sustainability into the core business. ST, a sample company, mentioned that they had a sustainability strategy and well-defined sustainability department at the corporate level, while the sustainability projects were implemented by various local teams (Corporate Responsibility Manager at ST, personal communication, August 24, 2015). This example provides some insights about the sustainability approach and delegation of CSR related tasks in a semiconductor company. IT, another sample company, highlighted that the global expanse of its operations required the support of hundreds of staff members for smooth implementation of sustainability-related projects (CSR communications manager at IT, personal communication, August 14, 2015). The president of every sample company was regularly informed about the progress of the sustainability programs and CSR reports by the head of the CSR department. Figure 6 provides an overview of the CSR department in a typical semiconductor manufacturing firm (UN CSR report, 2013).

Figure 6. Typical structure of CSR department. (Adapted from information presented in UN CSR report, 2013)

Although both companies from group 1 and group 2 had a sustainability strategy, the approach towards sustainability varied in each group. The sustainability strategy of group 1 companies simultaneously addressed a variety of social and environmental issues related to their operations. For example, SH, a company from group 1, had a multi-pronged approach to its sustainability, where the company performed LCA[3] of major products, conducted carbon footprint labeling[4], adopted a waste processing system, and voluntarily reduced the use of some hazardous chemicals. On the contrary, companies from group 2 had a limited vision, which was evident as they mainly targeted to achieve only the environmental regulatory requirements applicable to their operations. For example, RN and MR, both companies in group 2, focused primarily on GHG and waste reduction strategies. In RN and MR, the positive results of these two priorities were made tangible through participation in a carbon offset certificate program and achievement of a 100% waste diversion rate.

Every company's approach to sustainability is different. In addition, with sustainability being a slow process, the results of environmental and social initiatives may not be realized for several years, or even a decade. For example, ST, a sample company, mentioned that sustainability was its guiding principle for the past 20 years and that the experiences learned during this period are solely responsible for the maturity of its sustainability programs (ST sustainability report, 2014). The approach to

[3] Lifecycle assessment (LCA) is defined as a tool that enables systematic understanding of environmental aspects of a product or system through all its phases of lifecycle (UNEP, 2015)
[4] Carbon footprint labeling is a third party labeling system certified by the Korea's Ministry of Environment. It calculates the GHG emissions during a product's manufacturing, distribution, consumption and disposal phase (SKHynix, 2016)

sustainability in a company often depends on factors such as company priorities, stakeholder concerns, and industry benchmarks. Thus, to finalize the priority issues, materiality assessment was a rising trend among the sample. Conducting such an assessment helps companies identify key performance indicators (KPIs) portraying the social, environmental, and economic impact categories of their operations. The next sub-section elaborates the concept of KPIs and related observations from the sample.

Materiality assessment for identifying sustainability KPIs. Materiality assessment serves as a guiding principle for formalizing social and environmental priorities and choosing further actions to address these issues. According to KPMG (2014), materiality assessment involves determining, improving, and assessing the prospective socio-environmental impacts of the organization by identifying criteria known as key performance indicators (KPI) that indicate the company's strategy and goals. Some KPIs for the semiconductor industry are corporate governance, risk management, compensation and benefit, human rights, social involvement, sustainable environment, and product liabilities (UN CSR report, 2013). These KPIs are either quantifiable or descriptive. Companies usually identify 25-30 KPIs and address only five or six key concerns in one year's agenda.

Interviews and surveys usually guided the identification of KPIs for the sample companies when using GRI and Electronic Industry Citizenship Coalition (EICC) guidelines and stakeholder concerns. Most of group 1 companies (AD, IN, SH, and UC), along with few group 2 companies (NN, NV, and TS), had a systematic approach to involve stakeholders with the identification of key issues. The semiconductor industry

faces external stakeholder pressures on specific concerns such as climate change, energy usage, resource conservation, e-waste production and treatment, and water consumption (Villard, Lelah, and Brissaud, 2015). Because financial feasibility does not permit companies to address all concerns raised by stakeholders simultaneously (Lu, Wang, and Lee, 2013), a set of environmental and social issues is selected by setting short-term and long-term goals based on KPIs and the urgency of the problem. The progress of these goals is tracked annually through pre-determined timelines. The next sub-section describes this process further.

Long-term sustainability goals. The trend of setting long-term goals to reduce environmental impacts was more common in group 1 as compared to group 2. In group 1, four out of five companies set environmental goals that were aimed to be achieved by 2020. In contrast, IT was the only sample company that set social and environmental goals as part of the long-term strategy. The previous portion of this chapter lays the basis for the principles, policies, and outlook leading to an adoption of sustainability initiatives in a company, while the next sections describe the best practices specific for reducing the social and environmental impacts within the sample companies.

Manufacturing Related Sustainability Indicators

This section describes the sustainability best practices adopted by sample companies in their manufacturing operations. Risk management plans (RMP) or business continuity plans (BCP) utilize a plan-do-check-act approach to identify and mitigate risks associated with political unrest, natural disasters, economic downturns, infrastructure problems, fires, and explosions (SH sustainability report, 2015). As anticipated, both group 1 and

group 2 companies had concrete RMP for the company and throughout their supply chains. In the US, the environmental protection agency mandates all industries using hazardous chemicals to have an RMP in place (US EPA, 2015). Based on this observation, it is possible that other countries may have such regulations, which necessitates that companies prepare an RMP. For example, due to presence of a solid RMP, RO, a company from group 2, immediately assisted its suppliers in Thailand during the floods of 2011 to ensure employee safety and minimum capital loss (RO Innovation report, 2015). Similarly, environment health and safety (EHS) department is another vital division in semiconductor manufacturing companies that addresses employee safety and wellness. Every company from the sample had a well-defined EHS department.

Some companies adopted traditional best practices, such as projects for reduction of waste production, water consumption, and energy use, while some adopted advanced best practices, such as conducting an LCA of products, calculating carbon footprints, and measuring water footprints. For example, TK, a company from group 2, prioritized product sustainability over other traditional environmental aspects, such as waste, GHG, energy, and water. Thus, that every company's approach to sustainability is different was reiterated. The following sub-sections elaborate conventional sustainability practices, such as energy efficiency, water conservation, and waste reduction projects, along with the advanced sustainability techniques mentioned above.

Product compliance certification. European Union countries are at the forefront of product environmental protection through strict regulations, such as the EU Restriction of Hazardous Substances (RoHS), Registration, Evaluation, Authorization and Restriction

of Chemicals (REACH), Perfluorooctane Sulfonates (PFOS) Restriction, halogen-free, and EU Waste Electrical and Electronic Equipment (WEEE) standards. In addition to the EU RoHS regulation, countries, such as China, Norway, South Korea and United States (California), have developed similar regulations to prohibit the use of hazardous substances in electronics and electrical products (Wright, 2007). These directives are equivalent to non-tariff trade barriers, which restrict companies entering foreign markets (Luan, Tien, and Chen, 2015; Wang and Chiu, 2014). Thus, to gain a competitive advantage and ensure business continuity, all 20 companies from the sample followed every restriction applicable to their businesses globally.

End of life management is another best practice product compliance that ensures the appropriate management of products after exceeding usability. However, the sample companies had a business to business (B2B) model, which means the microchips and ICs produced by these firms were used in electronics, computers, and other consumer products of other companies. Consequently, the lack of interaction with end consumers has resulted in minimum investments in post-consumer use solutions (Corporate Responsibility Manager at ST, personal communication, August 24, 2015). In fact, AD, a company from group 1, was the only company that addressed the issue of end of life product management.

Energy efficiency projects. Group 1 companies from the sample were at the forefront for implementing projects to improve operational energy efficiency. According to SH, a company from group 1, the continuous increase of energy costs postulates a need to manufacture energy-efficient products that reduce manufacturing costs and provide a

competitive advantage (SH sustainability report, 2015). Group 1 companies that incorporated energy efficiency projects also acquired an ISO 50001 (energy management standard), which is an advanced certification that helps companies maneuver the complex path of achieving energy efficiency in manufacturing processes and products. Although the correlation between adoption of energy efficiency projects and ISO 50001 is established for this sample, the impacts of these two practices on energy consumption and GHG emissions is discussed further.

Additionally, renewable energy use is another way to reduce the consumption of the conventional *polluting* energy resources and offset carbon emissions. Although the use of renewable energy is widely discussed in academia and business, only 9 out of 20 sample companies from the sample either purchased green energy or installed solar and wind energy-capturing equipment in-house. Interestingly, only the companies from group 1 were interested in adopting these kinds of practices.

Water and ultra pure water conservation projects. Water use in a semiconductor fabrication facility is equivalent to that of a small town (The Engineered Environment, 2013). The manufacture of ICs requires several cleaning cycles with ultra pure water (UPW), which constitutes the majority of water usage in a fab. Despite the high magnitude of water use in the semiconductor manufacturing industry, only the group 1 (four out of five companies) and only one group 2 company adopted projects to conserve water. In addition, projects to reduce and reuse UPW were targeted only by group 1 companies, such as IN, TC, and IT, which is quite surprising, given growing global water scarcity.

Water scarcity may impact the semiconductor manufacturing industry as unavailability of regular water supplies, even for a single day, may lead to loss of multi-million dollars for such a water-intensive industry. A possible explanation to the least priority awarded to water conservation measures is evident from the statement by UC, a company with group 1, where they mention that "Our fabs use less than 5% water at the respective locations and thus, our impact on the water sources is not that significant" (UC CSR, 2014). In contrast, TC, another company from group 1, which has increased its production 2.5 times over the past 10 years, has simultaneously achieved 30% reduction of water usage per unit product (TC CSR report, 2014). Hence, water is a priority issue for only a few companies from the sample.

Waste reduction projects. Villard at al. (2015) found that the growing complexity of the chips has also increased the number of chemicals used during the manufacturing process. The chemicals used in the initial stages do not remain on the end product, as they get washed away as waste. Adoption of waste reduction projects is another best practice, which was adopted by majority of group 1 and group 2 companies from the sample. Interestingly, none of the group 1 companies targeted to achieve a 100% waste diversion rate, while three out of five companies from group 2 set this goal as part of their long-term strategies. Nearly 80% of the 20 sample companies incorporated measures to improve their waste recycling rates. Interestingly, RO, a company from group 2, had a recycling rate as high as 99.98% (RO Innovation report, 2015). A possible explanation of the wide adoption of waste reduction practices in the sample companies could be a result of stringent local waste regulations, such as the Resource Conservation and

Recovery Act (RCRA) in the US, and RoHS and WEEE in the European Union, and other regional RoHS laws.

GHG emissions and elimination of ozone depleting substances (ODS). Semiconductor manufacturing processes, such as plasma etching and plasma stripping, use chemicals such as hexafluoroethane, tetrafluoromethane, trifluoromethane, nitrogen fluoride, and sulfur hexafluoride. These chemicals have the potential to deplete the ozone layer. Despite the pressing issue of climate change, only the companies from group 1 set long terms goals to reduce GHG emissions and no company from group 2 set such targets. But, three out of five companies from group 2 and four out of five companies from group 1 voluntarily substituted chemicals with high global warming potential (GWP) with those having lesser GWP. Sustainability reports repeatedly mention that phasing out of some high GWP chemicals was difficult, because their unique characteristics made them essential constituents in manufacturing processes. As a result, only three out of five companies from group 1 completely eliminated the use of some ODS, while no company from group 2 followed this trend. In addition to the traditional approach described previously, companies adopted state of the art techniques to reduce the impacts of their products from manufacturing stage to end of life stage. The next sub-section describes these advanced techniques in detail.

Life cycle assessment, CDP disclosure, carbon footprint, and water footprint. LCAs are conducted by semiconductor companies to understand the impacts of their product from cradle to grave (i.e., from the raw materials to final disposal of the product). This approach provides a framework for designing and manufacturing green products that

enable ecological conservation and economic growth (Luan, Tien and Chen, 2015; Villard at al., 2015). Advanced techniques, such as LCA, carbon footprints, and water footprints of products are increasingly adopted by organizations to reduce the impacts of present and future generations of products. These assessments provide a better understanding of the product impacts with respect to inputs (water, energy, raw materials) along with externalities, such as wastes and emissions. LCA assessments were conducted by six out of 20 companies (i.e., 30% of the sample companies, of which only two were from group 1).

In the same manner, carbon footprints and water footprints calculate GHG emissions and water consumption during the manufacture of products. The practice of carbon footprints was more popular than water footprints in the sample. Carbon footprint calculations were conducted by six out of 20 sample companies for some or all of their products while four out of 20 sample companies analyzed the water footprint of their products. Interestingly, two out of five companies from group 1 and one out of five companies from group 2 engaged in carbon footprint calculations. On the other hand, calculating water footprints was only observed in group 1 companies, as 3 out of 5 conducted these measurements. In addition, the concept of ecodesign or design for the environment was commonly practiced by most of companies from group 1 (i.e., four out of five companies).

Similarly, participation and voluntary disclosure of selected environmental data for the Carbon Disclosure Project (CDP) was another advanced sustainability best practices adopted by some companies in the sample. CDP is a directory of voluntarily reported

data on GHG, with water and forest risk by organizations as a way to be accountable and transparent (CDP, 2016). The sustainability reports of the sample mention that only five out of 20 sample companies reported publicly in the CDP. Interestingly, the majority comprised of participants belonged to group 1 (4 out of 5 companies), such as AD, IT, SH, and UC, while NN was the only company from group 2 that engaged in this practice. Finally, this analysis highlights that SH and UC, both group 1 companies, are quite advanced in their approach to sustainability. These two companies adopted all four advanced best practices, which are assessing carbon footprint, conducting LCA, calculating water footprint, and disclosing GHG and water data in the CDP. This sub-section described the environmental best practices related to core manufacturing processes, whereas the next sub-section examines sustainability in peripheral processes, such as packaging, transportation, and building design.

Reusable packaging. Semiconductor manufacturing involves two major processes: chip production and packaging (protects chips during mounting on a printed circuit board). These two processes may take place at different global locations, making the dependency on transportation solutions high (Villard, Leah and Brissaud, 2015). As a result, the back and forth transportation of semiconductor products requires several layers of non-frictional packaging to prevent damage of these fragile products. Four out of 20 i.e., only 20% of the sample companies addressed the issue of eco-friendly packaging. The use of recycled material for packaging was the most common practice for reducing packaging waste. NN, a company from group 2, mentioned that the reduction of packing material by half allowed the transportation of more product in the same shipment size and

cut the shipment loading time by half (NN CSR report, 2013). Although reusable packaging has a very small footprint compared to the total resource use in the semiconductor industry, some companies are still addressing this issue.

Green transportation. Due to the complex nature of supply chains, transportation of semiconductor products is an inevitable part of this industry. Five out of 20 sample companies modified their existing transportation methods to reduce the associated carbon footprints. Group 1 companies, such as AD and IT, consolidated their warehouses and also converted transportation from air freight to water ways. UC, another group 1 company, switched to local purchasing as a way to reduce transportation costs, prevent supply chain disruption, boost local employment, and minimize carbon footprint. Another good example was presented by IT, a company from group 1, in which the company set progressive goals to reduce the carbon footprint of their transportation by converting 85% of the ground fleet from conventional to eco-friendly.

Green building certification. In addition to special projects to improve process efficiencies, companies are adopting a holistic approach to their manufacturing operations by acquiring green certifications for their manufacturing facilities. During an interview with CSR communications and disclosures manager at IT, which is a company from group 1, it was stated that retrofitting of old manufacturing equipments can be challenging and expensive (CSR Communications Manager at IT, personal communication, August 14, 2015). Thus, companies such as GF and TS already incorporated green factory certifications beginning from the construction phase of their new fabs. The practice of companies acquiring green facility certifications for new

facilities is growing steadily. UC and TS, two companies from group 1, had manufacturing facilities certified with Taiwan's green factory label[5]. These voluntary certifications recognize the firm's efforts to reduce the use of energy, UPW, and raw materials.

Similarly, the need to integrate sustainability into building design was gradually addressed by the sample firms, as evident from their adoption of US Green Building Council's Leadership in Energy and Environmental Design (LEED) building certifications. Eight out of 20 (i.e., 40% of the sample companies) had at least one LEED certified building, whereas, IT, a group 1 company, had 29 such buildings worldwide. The five companies from group 1 had all acquired LEED certification for at least one building, whereas three out of 5 of group 2 companies planned to obtain this certification during the next two years.

This section shed light on the best practices in areas of core manufacturing and other supporting processes while the next section describes the sample's approach to biodiversity conservation.

Ecological Responsibility

Various semiconductor manufacturing processes require thousands of solid, liquid and gaseous chemicals, which often leave their trails in air, water, and soil. The toxic release of metals and gases severely affects humans and aquatic life as a result of the manufacturing processes of semiconductors (Villard at al., 2015). The high levels of tungsten and other heavy metals found in Keya creek in Taiwan is a pertinent example of

[5] Taiwan's Green factory label is the world's first green certification system for factories which is based on green building construction and clean production (Eco-business, 2012).

this fact. The Keya creek receives treated wastewater from the biggest semiconductor manufacturing conglomerate in Taiwan (Hsu et al., 2011). MR was the only company from the sample that addressed its ecological responsibility holistically. An analysis of sustainability reports highlighted that very few companies from the sample discussed activities undertaken as part of their ecological responsibility. A detailed overview of this topic is provided in the next section, which assesses sustainability performance through analysis of environmental data from 2010 to 2014.

Supply Chain Related Sustainability

As the name suggests, this section describes sustainability best practices undertaken by companies to improve the functioning of their supply chain. Once sustainability practices adopted in-house mature, the same knowledge is passed on to suppliers to assist them with strengthening their sustainability management systems. Very few companies from the sample had stringent sustainability criteria to qualify their suppliers, but almost every company encouraged their suppliers to acquire ISO 14001 certification. Nearly 70% of the 20 sample companies mandated their suppliers to fill in the EICC's risk assessment template, titled self-assessment questionnaire (SAQ), annually. The SAQ is an efficient way to identify deficiencies of practices related to sustainability, ethics, and governance. Based on SAQ findings, SH and IN, which constituted group 1, assisted their subsidiaries, suppliers, and contractors to improve their sustainability management systems. Thus, these observations highlight that suppliers are not mandated to adopt sustainability practices, but are encouraged to adopt them voluntarily. Most suppliers of these sample companies were small and medium enterprises (SME). Interview with the

CSR Communications Manager at IT highlighted that firms are usually challenged by factors such as cost constraints and workforce unavailability, which limit the adoption of sustainability practices by these firms (CSR Communications Manager at IT, personal communication, August 14, 2015).

Social Aspects of Sustainability

In addition to best practices in the environmental aspects, the social impacts of the organization are also of great concern to stakeholders. Social violations can severely impact a company's public image and competitive advantage; thus, more companies are becoming diligent when addressing and preventing such impacts (Wang and Chiu, 2014). The following sub-sections describe the various best practices associated with the social facets of sustainability, such as human rights, wages, working hours, diversity, and employee and customer satisfaction.

Human rights policy and conflict minerals policy. Every company from the sample had the "normal" non-discrimination, no forced labor, no child labor policy as mandated by the Universal Declaration of Human Rights by the United Nations (1948). Similarly, the use of minerals originating from the conflicted areas of the Dominican Republic of Congo is another human rights issue of high concern to corporations, governments, and stakeholders. Tin, tungsten, gold, and tantalum are the four minerals required during the manufacture of semiconductors, and it is necessary that companies obtain these minerals from conflict-free areas. The Dodd-Frank Act (2010) dictates that companies listed on the United States Security and Exchange Commission (SEC) utilizing any of these four minerals in their products must follow this regulation. All of

the companies had a distinct conflict minerals policy, since they were listed in the SEC; however, IN, a company from group 1, voluntarily adopted this rule. Ten out of 20 i.e., 50% of the sample companies had well documented processes to ensure their suppliers obtained these minerals from responsible sources. The global e-sustainability initiative (GeSI) conflict-free minerals template assisted companies in their gathering of this data from their own operations, as well as from suppliers. IT, a company from group 1, is the only company in the world to produce microprocessors using tin, tungsten, gold, and tantalum, which are all procured from conflict-free sources.

Normal working hours and fair wages. A leading electronics company had to face the wrath of public outrage because one of its suppliers exceeded the standard working hours for employees. Based on this fact, it is understood that the semiconductor industry, which is a subset of the electronics industry, needs to be diligent in this matter. AD, a company from group 1 and RO, a company from group 2, were the only firms from the sample that followed the standard of one compulsory day off per week after 60 hours of working. Information on this aspect was unaddressed by most of the sampled companies. SC was the only sample company that prioritized the wellbeing, growth, and development of its employees over the traditional corporate social responsibility that usually stresses environmental initiatives.

In addition to normal working hours, fair wages is another factor that contributes to work satisfaction among employees. Due to the proprietary nature of the information, exact salaries were unavailable in the sustainability reports, but 13 out of 20 (i.e., 65%) of the sampled companies provided some information about employee wages. In addition,

employees of 10 out of 20 sample companies were entitled to at least minimum local pay and performance-linked bonuses. Similarly, 40% of the sampled companies offered stock options and shared profits with employees annually. All companies from group 1 encouraged career development of employees by offering tuition reimbursements. NN, a company from group 2, had a unique approach to reward its employees through annual bonuses, festival bonuses, and diligence bonuses during the mid-autumn festival, along with performance based incentives. IT, a company from group 1, also had a novel approach to their employee bonus system. The company's performance in customer surveys was linked to a specific bonus pay and two days of extra paid holidays. This acted like a domino effect where the employees felt motivated and performed their duties sincerely, which in return benefited the company economically (IT CSR report, 2014).

Employee and customer survey. Employee and customer surveys are considered best practices where costumers provide feedback about products and services, while employees voice their concerns about the company's operations and ethics. In the sample, 50% of the companies administered either a customer satisfaction survey or an employee survey. Customer satisfaction surveys and employee surveys each had similar adoption rates of 30% and 25%, respectively. The practice of conducting these surveys had no specific trends that could be linked to group 1 or group 2.

Diversity and inclusion. All 20 sampled companies had an equality and non-discrimination policy. IT and IN, both group 1 companies, specifically mentioned that they do not discriminate in employee compensation and promotions. Other companies may have adopted this practice, but no supporting data was available in the sustainability

reports. The number of men generally exceeds the number of women in any semiconductor manufacturing company. Surprisingly, in UN there were no female employees in managerial and vice presidential positions. In contrast, AS was the only sample company where female employees (51%) outnumbered male employees (AS CSR report, 2014).

Transparency and Benchmarking

Literature reviews highlighted that publishing legitimate information in a clear and understandable format increases stakeholders' trust towards the company. Third party assurance of sustainability data, description of fines and violations, adoption of sustainability benchmark certificates, and conducting facility audits are some of the best practices adopted by companies to increase transparency. The following sub-section illustrates these best practices further.

Third party assurance of sustainability report. Companies engage third party agencies to certify the accuracy of data published in sustainability reports. In the sample, 8 out of 20 (40%) companies partially or fully assured the sustainability data presented in the reports. Further analysis of this best practice is described in the next section about ecological responsibility.

Fines and violations. In the initial years of sustainability reporting, companies were disinclined to report information about accidents and fines. Later, as a way to facilitate a dialogue between the company and stakeholders, some firms began to publish sustainability reports containing true and unaltered information. A moderate number of companies (11 out of 20) from the sample portrayed information about violations and

fines in the sustainability reports. IT, a company from group 1, went a step forward by providing five years of historical data about monetary fines and violations to inform its stakeholders.

FS, another company from the sample, also described remediation efforts for 17 contaminated sites, along with the progress and costs associated with the clean up (FS CSR report, 2014). An explanation as to the disclosure of environmental liabilities in the US can be traced back to a mandate set by the *Statement of Position on Environmental Remediation Liabilities, SOP-96*, where the companies with environmental liabilities are obligated to disclose the associated environmental cleanup costs in their annual reports. Interestingly, information about environmental violations and fines were also published by companies not headquartered in the US, such as ST, TK, MR, TC, AS, UN, and UC. Even though voluntary disclosure of fines and violations has a positive impact on stakeholder support through added transparency, it may also demonstrate the company's incompetency to following the local and national environmental regulations. The next sub-section describes other voluntary measures adopted by companies to improve sustainability of their operations by streamlining process based standards set by organizations, such as ISO and OHSAS.

Sustainability benchmark certificates. The presence of guidelines or standards is necessary for a field like sustainability, which is quite vast and still emerging. Guidelines provide structure and direction for the company and act as industry benchmarks. ISO 14001 (environmental management system) and OHSAS 18001 (environmental health and safety system) were the two most commonly adopted sustainability standards in the

sample. These basic certifications streamline environmental management systems and reporting along with increasing transparency, which is a major stakeholder expectation (Tyteca et al., 2002). In addition, these standards are useful to companies, which are export-oriented, as they broaden markets for the company (Luan, Tien, and Chen, 2015). The early adopters of these certifications gained a competitive advantage over their rivals. The popularity and usage of other advanced sustainability standards, such as ISO 50001 (energy management systems) and ISO 14064-1 (quantification, reporting and removal of GHG) was a trend observed mostly by companies from group 1. Interestingly, six out of 20 (i.e., 30%) of the sample companies already adopted ISO 14064-1 certification, which indicates that the companies are interested in attesting the environmentalism of their products (Luan, Tien and Chen, 2015). The practice of utilizing advanced standards, such as the European EMAS certification (environmental management), ISO 14067 (GHG- carbon footprint), ISO 14010-1 (life cycle assessment), and PAS 2050 (product carbon footprint) was also another trend emerging in group 1 companies. In contrast, SC, a company from group 2, was the first semiconductor manufacturing company in the country to adopt ISO 14064-1 and GPMS hazardous substance management certificate (SC CSR report, 2013). In spite of the increasing popularity of these benchmarking standards, these environmental and social certifications do not guarantee performance and instead provide systematic guidelines for streamlining internal processes to achieve set goals.

Facility audits. Conducting facility audits is another way to ensure correct functioning of management systems. Every company from the sample performed regular

sustainability audits at in-house facilities and supplier sites. According to RO, a company from group 2, it was mentioned that EICC audits and 3rd party audits increase transparency (RO Innovation report, 2014-15). These audits were usually based on the EICC standard questionnaire. The practice of auditing measures the current status of the environmental and social impacts of the company's activities based on the standardized process, and also sheds light on any deviations. Five out of 20 sample companies engaged third-party agencies to conduct facility audits. In addition, the reported non-conformances observed during the audits were immediately addressed and remedial measures were taken (UC CSR report, 2014).

The Electronic Industry Citizenship Coalition (EICC) and World Semiconductor Council (WSC) are the two organizations that created an impact on semiconductor manufacturing companies across the world. The standards set by these two organizations act as benchmarks that serve as guidelines while deciding sustainability strategies. EICC audits also determine ethical issues in an organization and the presence of zero ethical violations is a noted best practice. IT, a company from group 1, briefly described ethical violations in the company in its sustainability report. SC, another sample company, tabulated ethical violations observed during its supplier audits in the sustainability report. Thus, it can be stated that ethical issues either did not occur in the other companies from the sample or they were not reported publicly.

Summary

In the sample, the approach to environmental aspects was holistically addressed as compared to social impacts. Most companies addressed several environmental aspects,

but lacked in initiatives for seeking social equity. When environmental best practices were analyzed, companies adopt best practices that improved sustainability in the core manufacturing processes as well as in the peripherals. In addition, ecological responsibility was one of the most underrated issues in the sample companies.

All the previous observations reiterate that group 1 and group 2 followed distinct trends in the adoption of best practices. Group 2 companies mostly adopted best practices from a regulatory standpoint, which is the first step in the corporate sustainability adoption process as described by Brusman (2009). In contrast, group 1 companies incorporated several advanced green processes along with practices adopted by group 2 companies. Since the types of best practices adopted by group 2 were not as advanced as those in group 1, group 2 depicts developing companies with respect to sustainability adoption, while group 1 comprises of progressive companies. This differentiation of the two groups as progressive and developing provides deeper insights about the two polar cases of companies due to their distinct characteristics. The same approach is used for the further analysis on social and environmental trends.

Results and Analysis: Sustainability Performance Based on Trends

The previous section dealt with categorizing sustainability performance of the sample companies on the basis of adoption of best practices. This chapter continues the discussion about sustainability performance by emphasizing the overall trends of environmental and social data among the 20 sampled companies. This portion of the research analyzes the socio-environmental performance of the sample companies during the years 2010 through 2014, based on seven impact criteria: water consumption, energy usage, waste production, GHG emissions, other air emissions, ecological responsibility, and social impact. Table 7 of this report lists the parameters for which the trend analysis was conducted. Since the size of sample companies varied, it was crucial to use normalized data to reach a fair comparison of the impacts of each company. Normalized data with consistent common denominators (e.g., net revenue or unit production) was used to compare common units of analysis. Researchers, such as Krajnc and Glavic (2005), mention that normalized data may hide trends of absolute data, which are of most concern to stakeholders. Hence, absolute data about environmental parameters, which depict the overall resource consumption and emission trends of individual companies, were also examined to support the trends observed in normalized data. Additionally, social initiatives and investments, which were historically underrepresented in CSR, are also discussed in this chapter. Table 16 illustrates an example of normalized data and the supporting absolute data, which provide insight into the underlying trends of the normalized data of a company.

Table 16
Example of absolute and normalized data for water usage

Data	Description	Year				
		2010	2011	2012	2013	2014
Normalized data	Water usage per unit product (m^3/wafer m^2)	11. 8	12.7	13.1	13.6	14.7
Supporting absolute data	Water intake from tap water, condensate and rainwater (million m^3)	78.5	90.7	90. 8	89.9	87. 2

Source: Data obtained from UC CSR report, 2014

The sample for this research study is comprised of semiconductor manufacturers. Therefore, a typical unit of production, such as a Silicon chip, wafer, or semiconductor material layer is used as a common denominator for normalizing data about resource use and emissions. In addition, some companies normalized environmental data with reference with net revenue. The dominant resource use or emission trends of the sample were analyzed by grouping companies by common denominators (e.g., unit production or net revenue). If three or more companies followed the same pattern over 2010-2014 data, it constituted as a trend for the environmental criteria and sub-criteria described in Table 7 of the report. The graphs shown in this chapter are representative examples of the dominant trends observed for the five environmental criteria. The data for these 20 sample companies showed three dominant trends: (1) decrease, (2) increase, or (3) mixed.

Since data analysis represents resource use and emissions of the sample companies during the 2010 through 2014 period, a decreasing trend shows that the company reduced its manufacturing inputs and also emission externalities. Thus, it is evident that the company is causing less harm to the environment, which can be regarded as good performance. Similarly, if an increasing trend is followed by the normalized environmental data, it indicates an increase in resource use or emissions, which denote

that more resources were put in and more harmful gases were emitted. Hence, there is no doubt that this increasing trend shall prove to be harmful to the environment. The third tendency, mixed trend, in the environmental data provides no distinct explanation of the resource use or emissions.

In contrast, ecological responsibility and social impact were the two criteria which contain more descriptive data than quantitative data. Thus, a descriptive analysis of these criteria was conducted to comprehend underlying trends. In addition to qualitative data, the companies also presented quantitative data related to social well-being, such as total social investments, percentage of women and disabled employees at the workplace, employee training and development costs, total employee volunteer hours, Occupational Safety and Health Administration (OSHA) severity and incidence rates, and total number of employees in the organization. The available quantitative data about social aspects were represented in absolute terms or as descriptions. Similar to environmental data, a trend analysis was conducted for quantitative social data. After analyzing the absolute data trends, it was found that an increase or constancy of the social data indicated that the company increased its investment in human capital and social initiatives to ensure social development. Similarly, a decrease of quantitative social data indicates a cut down in investments and volunteering, which to some extent hinders the development of society. Thus, the interpretation of environmental trends is diametrically opposed to social trends. The next sections shed light on the environmental and social trends observed in the sample and discuss the causation of these underlying trends.

Environmental Trends

Energy demand. Electricity is the fuel source most utilized in semiconductor manufacturing processes. According to the sustainability reports of the sample companies, electricity accounts for 55-95% of the industry's total energy requirements. In addition, secondary fuels, such as natural gas, diesel, liquid petroleum gas, fuel oil, and nuclear energy are also used in small proportions, depending on their availability and applicability to manufacturing processes. Surprisingly, manufacturing tools accounted for only 35% of the energy usage in a fab, while most of the electricity is utilized in systems that maintain a dust-free environment, ensure ventilation, and produce UPW. Assessment of energy use by the sample companies is based on electricity consumption and natural gas usage, as these two energy sources were the primarily used by the sample companies (LBNL, 2000). The next sub-sections describe the trends observed for electricity consumption and natural gas.

Electricity consumption. Electricity is required to run manufacturing equipment as well as maintain cleanliness and air flow in clean rooms. The sustainability reports of 13 out of 20 (i.e., 65%) sample companies published normalized data about electricity usage, typically in terms of electricity consumption per unit of production and electricity usage per net revenue.

Electricity consumption with respect to revenue. Figure 7 represents a decreasing trend of electricity usage, with respect to net revenue. Since three out of 20 or 15% of the sample companies followed this data trend, it is indicative that addressing energy efficiency was relatively an uncommon trend for the sample firms.

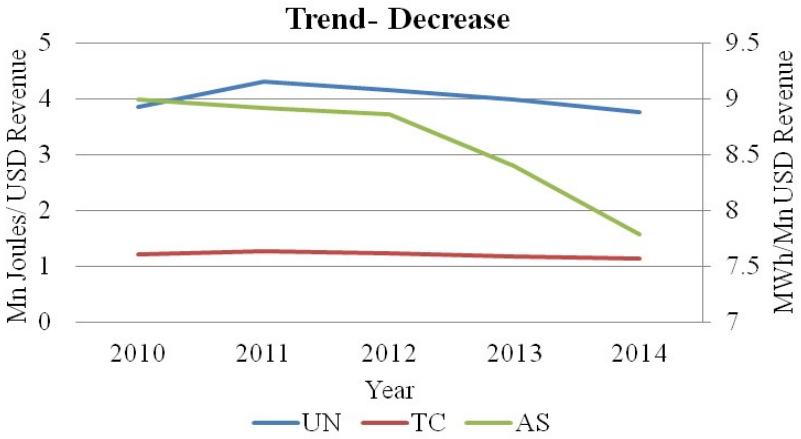

Figure 7. Electricity use/net revenue (Source: Data extracted from 2010-2014 sustainability reports of TC, UN, and AS)

UN, AS, and TC were the three companies that followed the decreasing trend represented in Figure 7. These three companies increased net revenue and electricity usage in absolute terms over 2010 through 2014, which is quite contradictory to the trend observed in Figure 7. A possible explanation to the above trend could be based on the fact that companies were recovering during the initial years of the economic recession of 2009-2010 and gradually as production stabilized (2012-2014), electricity usage began to decrease, which is indicated by 6%-10% reduction of normalized electricity usage in 2014, as compared to 2010.

Electricity consumption with respect to unit production. The analyzed sustainability reports highlighted that eleven out of 20 (i.e., 55%) of the sample companies disclosed data about electricity consumption per unit production. The most dominant trends observed in the data are presented in Figure 8 and Figure 9.

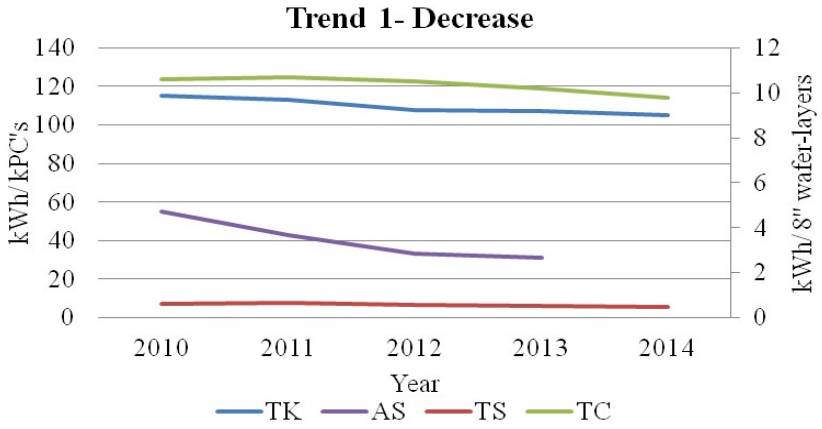

Figure 8. Electricity consumption/unit production (Source: Data extracted from 2010-2014 sustainability reports of TK, AS, TC, and TS)

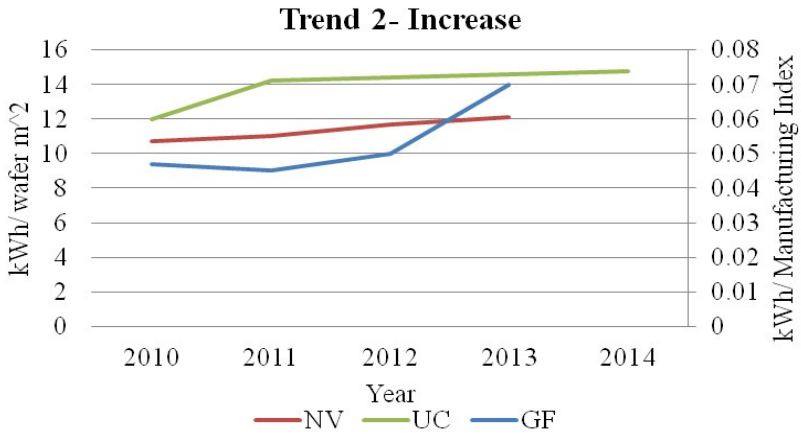

Figure 9. Electricity consumption/ unit production (Source: Data extracted from 2010-2014 sustainability reports of NV, UC, and GF)

Out of the 11 companies that published normalized data about electricity consumption, four out of eleven followed an increasing trend (Figure 8) and six out of eleven companies followed a decreasing trend (Figure 9), while no distinct trend was observed by one company. The sample companies that followed the decreasing trend were TC, NV, ST, TI, TK, and IT (Figure 8), while the companies SH, UC, GF, and AD followed an increasing trend (Figure 9). In Figure 9, the manufacturing index (MI) is a standardized measuring unit developed by company GF from wafers produced, the

number of masking steps in the fab, and the total area of wafers made when normalized with annual performance data to manufacturing levels (GF Sustainability report, 2015). Adoption of energy saving best practices and incorporation of renewable energy could be the two prominent reasons driving the decrease of normalized values of electricity over the years.

The four companies that increased total electricity consumption in normalized terms also increased their electricity usage in absolute terms from 2010-2014. Since none of the companies publicly disclosed the quantity of units sold for proprietary reasons, the net revenue and sales can be an approximated representation of the number of units sold (unit production). A possible explanation for the increased trend of electricity consumption could be the increased net revenue/sales and a rise of absolute electricity consumption over 2010-2014.

Based on these trends, there is no doubt that companies are incorporating measures to reduce electricity consumption to GHG emissions and increase cost savings in the long run. Although the adoption rate of best practices, such as energy projects, was low in the sample, it was found that companies were slowly embracing production-oriented and behavioral changes to improve energy efficiency. Table 17 illustrates some commonly adopted energy saving measures by the sample firms.

Table 17.
Energy-saving measures adopted in the sample companies (n=20)

Sustainability best practice categories	Electricity saving measures	No. of companies
Green building certification	Adoption of LEED green building certification	8
Energy efficiency projects		
	Purchase of renewable energy	8
	Replacing fluorescent lights with LED lights	7
	Setting optimal temperature for AC and chillers	5
	Use of heat exchangers to utilize waste heat	4
	Replacing and retrofitting old manufacturing equipment	4
	Use of automated switches and proximity sensors in office and factory	4
Product sustainability	Product innovative to reduce energy usage	4

Natural gas usage. Natural gas is used in small quantities for operating boilers and volatile organic compound (VOC) treatment systems in semiconductor manufacturing processes (UC CSR report, 2014). Five out of 20 (i.e., 25%) of sample companies published normalized data about natural gas consumption in their sustainability reports. Publishing normalized data about natural gas consumption, with respect to unit production, was more common as compared to net revenue.

Natural gas usage with respect to unit production. Since only 15% of the sample companies published data about natural gas usage, it is evident that reducing natural gas consumption was not a high priority issue among the sample companies.

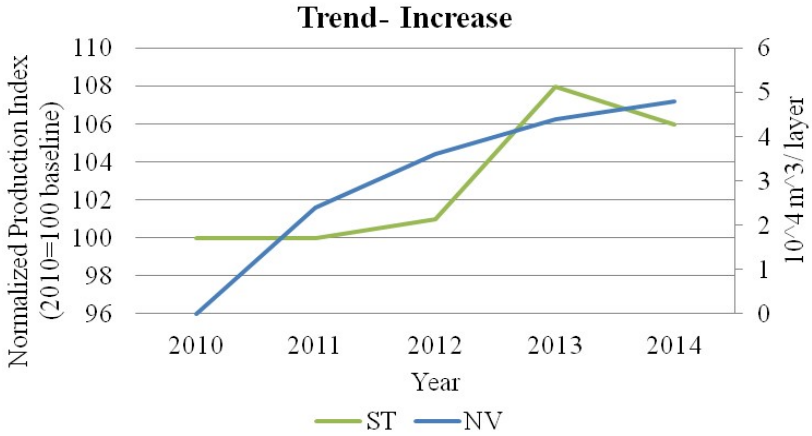

Figure 10. Natural gas consumption/ unit production (Source: Data extracted from 2010-2014 sustainability reports of ST and SH)

The three companies that followed the increasing trend (Figure 10) were SH, ST, and NV. Due to limited availability of data about this parameter, the key drivers behind the increase of normalized natural gas consumption are unknown. Although the sustainability reports of some sample companies mentioned an adoption of measures to improve efficiency of boiler and VOC equipment, these efforts were not reflected in any of the data trends. This section described the trends of energy usage; the next section explores water-related trends in the sample.

Water Consumption. This section describes the data trends of total water consumption and wastewater generation.

Total water consumption. After electricity and Silicon, water is the most important raw material used in the semiconductor manufacturing process. Most processes for semiconductor manufacturing use high-quality, pure water, and the production of this ultra pure water (UPW) is both water and energy intensive. Water stress, due to use of UPW, is a major impact of the semiconductor industry (Villard, Lelah and Brissaud, 2015). According to Robert Donovan, a process engineer at the Sandia National

Laboratories, about four gallons of municipal water yields only 2.5 liters of UPW. Since the recovery rate of the UPW production process is between 60-75%, municipal water input requirements are far more than what is actually required (Donovan, 2002). Surprisingly, only 50% of the sample companies set long-term goals to reduce water use. In addition, water consumption was one of the most commonly reported parameters in the sample, and hence it can be noted that it was a high priority issue of the sample companies.

Total water consumption with respect to revenue. An analysis of the sample sustainability reports emphasize that publishing normalized data about water consumption, with respect to net production, was more prominent as compared to net revenue. UN and AS were the only companies that published data about water consumption per net revenue, and no specific trend was observed for these two companies. One company reported a 38% increase from 2010-2014, while the other decreased its water withdrawal intensity by 18% over the same period.

Total water consumption with respect to unit production. The analysis of sustainability reports highlights that a high percentage (eleven out of 20 i.e., 55%) of sample companies reported their normalized water consumption with respect to unit production. Out of eleven companies, eight significantly reduced water used per chip, while the remaining three companies increased their normalized water use over the period 2010-2014. The Figure 11 describes the most dominant water use related trend observed in the sample.

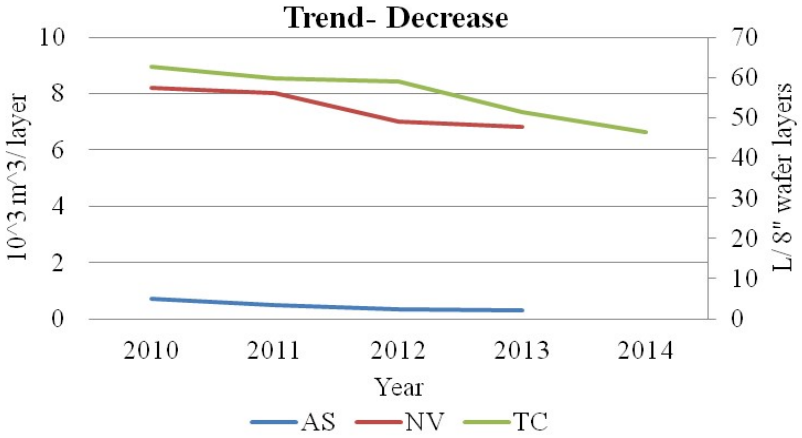

Figure 11. Total water consumption/unit production (Source: Data extracted from 2010-2014 sustainability reports of in AS, NV, and TC)

Figure 11 exemplifies a decreasing trend of water use per unit production utilized by the eight sample companies (AS, TC, SC, ST, NN, NV, TS, and IT). These eight companies reduced water usage per unit production by a minimum of 7% to 8% from 2010-2014. Wastewater categorization, reuse of UPW during the manufacturing process and use of recycled water for non-potable applications, could be some of the best practices that stimulated this decrease. In addition, few companies had water usage policies and water discharge standards, which were stricter than the applicable local regulations. Similarly, water recycling rates progressed over the years and some were as high as 95%. If technological advancement could increase the recovery rate of UPW to 90 to 95%, it would be beneficial to the semiconductor industry. Such improvements shall prepare semiconductor companies to tolerate or reduce water scarcity in areas where their facilities are located.

Wastewater generation. Since water is an important resource for semiconductor manufacturing, the production of wastewater is an inevitable part of operations. Very few sample companies (i.e., four out of 20) published data about wastewater production

per unit manufactured. Since only 20% of the companies from the sample published this data, reporting normalized data about this parameter was relatively uncommon in the sample.

Wastewater generation with respect to unit production. Out of the four companies that published data about wastewater generated per unit production, two followed a decreasing trend (Figure 12), while two followed an increasing trend (Figure 13).

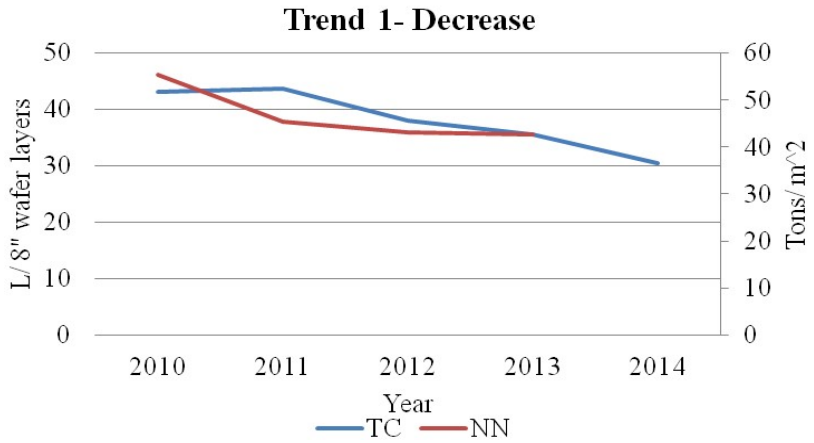

Figure 12. Wastewater generation/ unit production (Source: Data extracted from 2010-2014 sustainability reports of TC and NN)

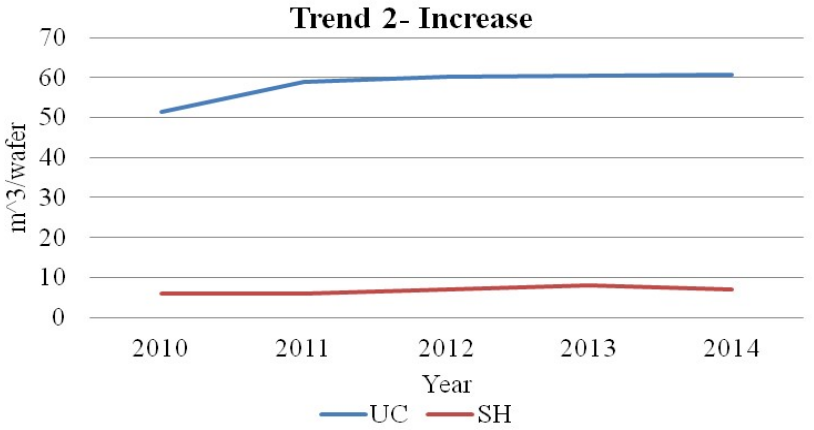

Figure 13. Wastewater generation/ unit production (Source: Data extracted from 2010-2014 sustainability reports of UC and SH)

Despite this mixed trend, all four companies gradually stabilized wastewater generation during 2013-2014. Water recycling rates are an important indication of water management efficiency in a company and as mentioned above, recycling rates are improving in the sample companies. Nearly 50% of the sampled companies invested in infrastructural facilities and pollution abatement equipment. Some companies also adopted water related project best practices, but most of these measures targeted reduction of water usage in peripheral areas (e.g., buildings, toilets, etc.) and not in manufacturing processes. The increasing scarcity of water resources needs to be addressed by sample companies by maximizing the use of incoming water and minimizing wastewater discharge into local water bodies and municipal sewers. Some common measures adopted by the sample companies to reduce their water footprint are listed in Table 18.

Table 18.
Measures adopted to reduce water footprint (n=20)

Sustainability best practice categories	Measures adopted to reduce water footprint	No. of companies
Long term goals	Long-term goals on water-use reduction	7
Water conservation projects	Reusing process water into cooling towers and scrubbers	5
	Use of recycled non-potable water in urinals and landscaping and rainwater harvesting	3
	Investment in on-site wastewater treatment plants	2
	Optimizing water use during wafer washing	2
CDP disclosure and carbon-water footprint	Disclosure of water footprint in the Carbon Disclosure Project (CDP)	2

Waste production. Sustainability reports from the sample companies repeatedly mention that increased chip complexity has a high impact on waste generation. To capture a holistic view of waste production in this industry, this study analyzes the trends of total solid waste, hazardous waste, and non-hazardous waste.

Total solid waste production. Publishing normalized data about total solid waste production was a remarkably uncommon trend, because only five out of 20 (i.e., 25%) of the sample companies presented this data in sustainability reports. The trends of total waste production data, with respect to net revenue and net production, are discussed below.

Total solid waste production with respect to revenue. Surprisingly, only one company presented data about waste production normalized, with respect to revenue. RO was the only company that followed a decreasing trend where the company reduced its normalized waste production by 31% from 2010-2014. A few possible explanations of the decreasing trend are (1) a reduction of total waste generation and (2) an increase of revenue and decrease/consistency of total waste generation. Another alternative explanation for this decrease could be the recovery from the 2009 global financial crisis, which may have stabilized waste production after the initial slow down in 2010-2011.

Total solid waste production with respect to unit production. Only four out of 20 sample companies disclosed data about total solid waste production per unit production, of which three followed the mixed trend represented in Figure 14.

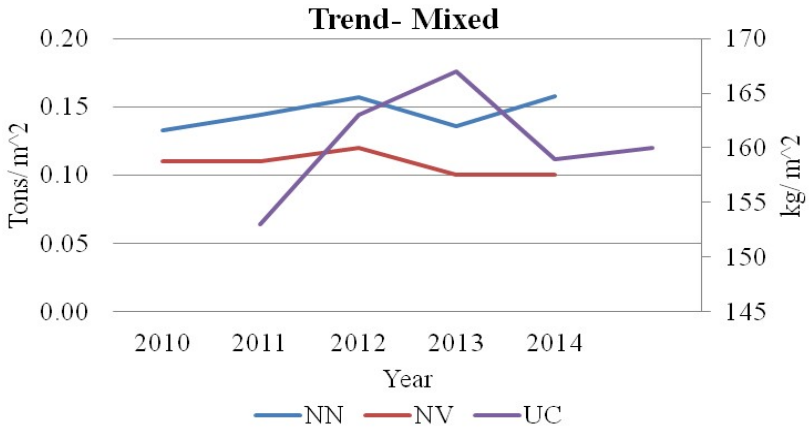

Figure 14. Total solid waste produced/ unit production (Source: Data extracted from 2010-2014 sustainability reports of NV, NN, and UC)

UC, NV, and TS were the three companies that followed the mixed trend over 2010-2014 (Figure 14). Some key factors driving the mixed trend could be (1) a difference of waste recycling rates, (2) changes of waste segregation methodologies, (3) increased absolute waste production over 2010-2014, and (4) increased complexity of the chips. In addition, a negative trend (i.e., increase of waste incineration rate) was also observed in these three companies. Thus, based on these contradicting factors, it is difficult to reach a reasonable explanation for this mixed trend.

Hazardous waste production. Data about hazardous waste production was published by four out of 20 (i.e., 20%) companies from the sample, and normalization with respect to unit production was more common, as compared to net revenue. The low percentage of companies publishing data on this topic demonstrates that reporting of hazardous waste was uncommon in the sample.

Hazardous waste generation with respect to unit production. It was noted that all four companies that published normalized data about hazardous waste followed an increasing trend as presented in Figure 15.

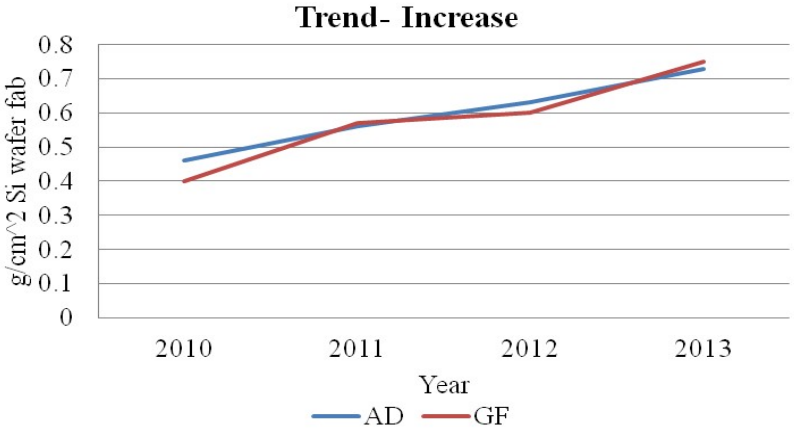

Figure 15. Hazardous waste production/ unit production (Source: Data extracted from 2010-2014 sustainability reports of AD and GF)

The four companies that followed the increasing trend (Figure 15) were UC, GF, IT, and AD. Each of these four companies increased hazardous waste produced per unit by a factor ranging from 27% to 88% over 2010-2014. Such a high increase of normalized hazardous waste production is undoubtedly due to increasing complexity of the chips. The use of chemicals during the different manufacturing processes has increased, thus resulting into greater quantities of waste. Another possible contributor to this trend could be the changes of waste segregation classifications and waste discharge regulations.

Non- hazardous waste production. Any substance that does not fall under the definition of hazardous waste is defined as non-hazardous waste. Only three out of 20 (i.e., 15%) sample companies published data about normalized non-hazardous waste production, which indicates that publishing data about non-hazardous waste was an uncommon trend in the sample.

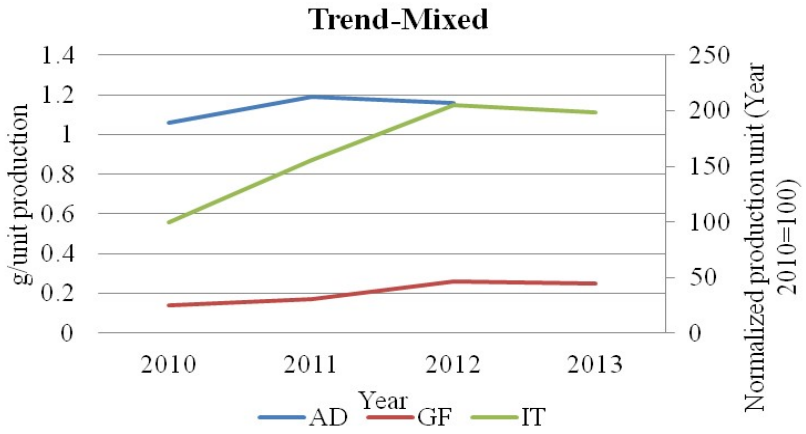

Figure 16. Non-hazardous waste produced/unit production (Source: Data extracted from 2010- 2014 sustainability reports of AD, GF, and IT)

AD, IT, and GF were three companies that followed the mixed trend (Figure 16). Each of these companies increased non-hazardous waste production per unit production by 9%-79% over 2010-2014. This trend could be supported by the fact that total non-hazardous waste production increased in absolute terms over 2010-2014. It was also observed that two out of these three companies were constructing new fabs during 2012-2013, which was identified as the key reason for the increase of non-hazardous waste during those years. Although non-hazardous waste production has increased with respect to the 2010 baseline, there is a moderate decrease from the year 2012-2014, which indicates companies may have incorporated some measures to reduce, segregate, and recycle wastes. These measures are gradually bearing fruit. Some of the prominent measures undertaken by companies to reduce their total waste production are listed in Table 19.

Table 19
Waste reduction measures adopted by sample companies (n=20)

Sustainability best practice categories	Waste reduction measures	No. of companies
Long term sustainability goals	Long-term goals to reduce total waste	7
Reusable packaging	Use of reusable and sustainable material for packaging	6
Waste reduction projects	Reuse of process chemicals* from waste stream	5
	Sale of outdated manufacturing equipment and office electronics	3
	Metal recovery and reuse	3
	Reuse of Silicon 'test' wafers and sale of waste wafers to solar manufacturers	2
	Composting cafeteria waste	1
Life cycle assessment	"Take back waste" initiatives for electronic waste	1

**Note.* Chemicals such as Sulfuric acid, Isopropyl Alcohol, Copper Sulfate, and Ammonia.

Greenhouse gas (GHG) emissions. Normalized data of GHG emissions were the most reported parameter in the sample. The report analysis highlighted that 14 out of 20 (i.e., 70%) of the sample companies reported normalized values for total GHG emissions, or scope 1 and scope 2 emissions. The high percentage of companies reporting this normalized data makes it clear that it is a common industry practice. Interestingly, all 20 companies in the sample had short-term and long-term goals for reducing GHG emissions. Some companies were vanguards of GHG reduction measures and already surpassed the milestones set internally. In addition, the adoption of ISO 14064-1

certification, a system for adopting measures for reducing GHG emissions and reporting, also increased in the sample.

Total GHG emissions. Quantitative analysis highlighted that three companies normalized total GHG emissions, with respect to net revenue and seven companies normalized this data with respect to net production. The data trends for each of these two normalizations are presented below.

Total GHG emissions with respect to net revenue. Only three companies presented normalized data with respect to net revenue, of which two followed the decreasing trend presented in Figure 17.

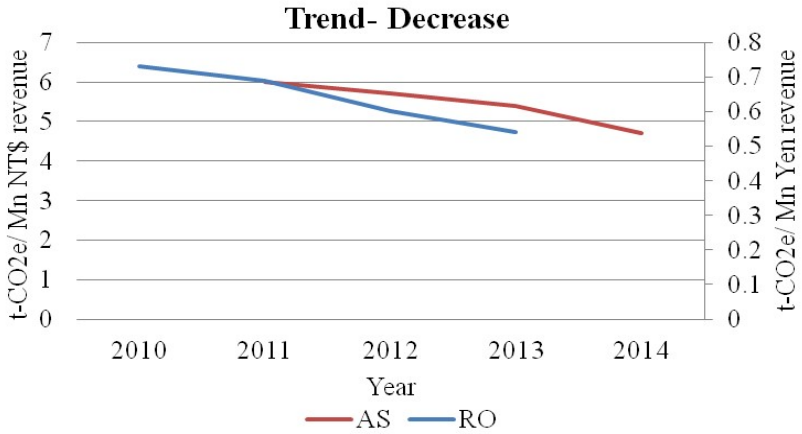

Figure 17. Total GHG emissions/net revenue (Source: Data extracted from 2010-2014 sustainability reports of RO and AS)

RO and AS were the two companies that followed a decreasing trend, and some possible explanations of this change during 2010-2013 are (a) increased production, (b) lower or constant absolute values of GHG emissions, and (c) stricter local and international GHG regulations. Interestingly, RO and AS followed in-house pollution control standards that were stricter than the local regulations. Improved transparency of GHG emissions was achieved through voluntary disclosure of carbon footprints in the

Carbon Disclosure Project by some sample companies. In addition, 40% of the sample companies also hired third-party agencies to validate and certify their GHG data to add credibility to GHG disclosures.

Total GHG emissions with respect to unit production. Interestingly, seven out of 20 (i.e., 35%) of sample companies reported GHG emissions per unit produced and the data followed a mixed trend, as presented in Figure 18.

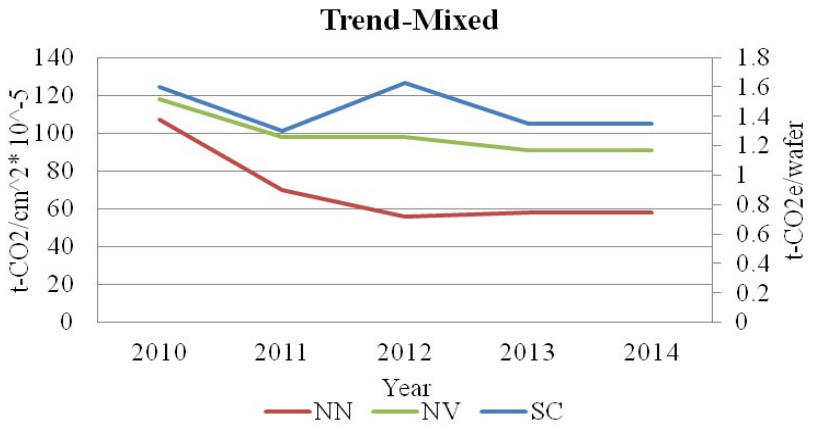

Figure 18. Total GHG emissions/ unit production (Source: Data extracted from 2010-2014 sustainability reports of SC, NN, and NV)

Seven sample companies (NN, SC, GF, AS, ST, NV, and IT) followed the mixed trend as observed in Figure 18. Some reasons for this mixed trend could be (1) international efforts and regulations for reducing GHG emissions, (2) investments in measures to reduce carbon footprint, and (3) stabilization of GHG emissions after the 2009 economic crisis. Electricity consumption is one of the largest sources of GHG emissions in the semiconductor industry, and it is expected that adoption of energy saving projects could curb GHG emissions to some extent. The magnitude of the energy savings is evident from the example of TS, a sample company which has adopted 181 energy

saving projects that have saved $4.5 billion and have offset 46,000 t-CO_2 from the atmosphere (TS Citizenship report, 2014).

The next two sub-sections describe emission trends for scope 1 and scope 2 GHGs with greater detail.

Scope 1 emission. Scope 1 emissions are the direct GHGs emitted by company manufacturing processes, energy usage, and fugitive emissions from septic tanks and firefighting equipment (UC CSR report, 2014). Only four out of 20 (i.e., 20%) of sample companies published data about scope 1 emissions per unit of production, and none normalized scope 1 emissions with respect to net revenue.

Scope 1 emission with respect to unit production. Only four out of 20 (i.e., 20%) of sample companies published normalized data about this parameter, which clarifies that publishing GHG data differentiated as scope 1 emissions were an uncommon practice in the sample. Out of the four companies, three steadily decreased scope 1 GHG emissions per unit, as presented in Figure 19.

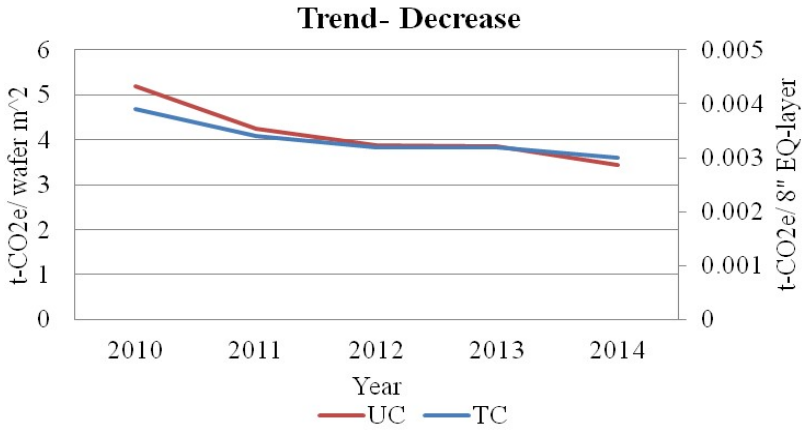

Figure 19. Scope 1 emissions/ unit production (Source: Data extracted from 2010- 2014 sustainability reports of UC and TC)

UC, AD, and TC were the three companies that demonstrated the decreasing trend as presented in Figure 19. Some factors behind this decreasing trend could be (1) increased adoption of advanced techniques, such as ISO 14064-1 certifications for manufacturing facilities, which provide more reliability to company GHG reduction strategies and increases accountability towards stakeholders, and (2) increased outsourcing of manufacturing.

In contrast, SH was the only company from the sample that increased normalized scope 1 emissions over the indicated period. This upward trend could be linked to capacity expansions of existing facilities and construction of new production units. One company from the sample mentioned that their scope 1 emissions increased due to technical changes of processes. The decreasing trend presented in Figure 19, could not be supported by the absolute data about scope 1 emissions, because out of the eleven companies that disclosed this information, six decreased their emissions, while five increased emissions over 2010-2014.

Scope 2 emissions. Scope 2 emissions are emissions released from purchased electricity and steam utilized by the company. Scope 2 emissions contribute greatly to total GHG emissions by the semiconductor industry, because this industry is largely dependent on purchased electricity for powering its processes. Only three out of 20 (i.e., 15%) of the sample companies published normalized GHG data differentiated as scope 2 emissions.

Scope 2 emissions with respect to unit production. Publishing data about this topic was not a common practice in the sample, because only 15% of companies presented

normalized data about this parameter. Out of the three companies, two slightly reduced scope 2 emissions per chip, as illustrated in Figure 20.

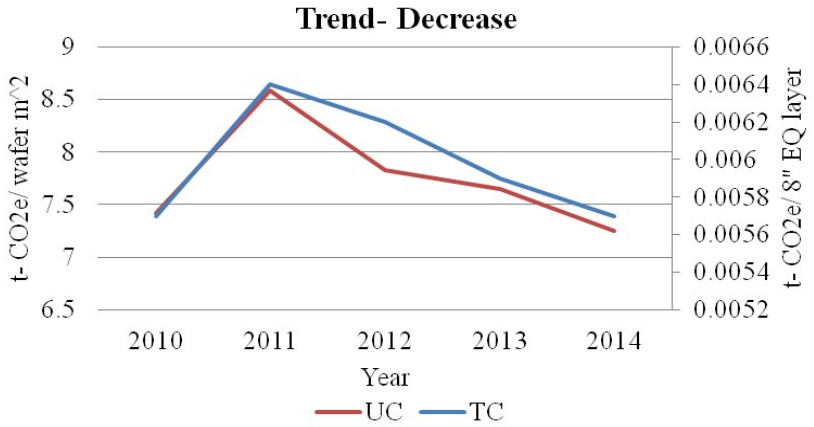

Figure 20. Scope 2 emissions/ unit production (Source: Data extracted from 2010-2014 sustainability reports of UC and TC)

UC and TC followed the decreasing trend shown in Figure 20. In absolute terms, these companies exhibited a mixed trend of total scope 2 emissions from 2010 to 2014. Based on this observation, it is difficult to explain the decreasing trend of normalized data of scope 2 emissions. Some best practices, such as adoption of energy saving measures and retrofitting old equipment to increase energy efficiency may have factored into a decrease of the trend. In addition, increased production after the 2009-2010 financial downturns could be another reason for the reduction of per unit Scope 2 emissions. Given this situation, scope 2 emissions peaked in 2011 and gradually decreased after the adoption of certain energy saving measures and stabilized during later years.

Based on these findings, it was observed that companies described measures to reduce the overall carbon footprint in greater detail; some of the prominent measures adopted are listed in Table 20.

Table 20
Measures adopted to reduce carbon footprint (n=20)

Sustainability best practice categories	Measures adopted to reduce carbon footprint	No. of companies
Long term sustainability goals	Setting long-term goals to reduce GHG emissions	8
Energy efficiency projects	Purchase or installation of green equipments	8
Sustainability benchmark certificates	Adoption of ISO 14064-1 certifications	6
CDP disclosure and carbon-water footprint	Transparency and accountability through Carbon footprint disclosure in CDP	6
Climate change and elimination of ODS	Redesigning manufacturing processes to find alternatives to GHG's and ODS	4
Green transportation	Utilizing waterways *vis-a-vis* air freight in transporting	4
	Installation of electric vehicle charging stations on site	3
	Use of mass transportation and bicycle tracks for employee commute	2
	Centrally located warehouses and consolidation of storage facilities	2

Other air emissions. This section describes the patterns noted in Volatile Organic Compound (VOC) and nitrogen oxides (NOx) emissions in the sample from 2010- 2014.

Volatile Organic Compound (VOC) emissions. VOCs emitted from manufacturing equipment damaged local air quality and caused summer smog, which is an area of concern for the semiconductor manufacturing industry (Villard et al., 2015). An investigation of VOC emission data by the sample companies highlighted that reporting normalized data about Volatile Organic Compound (VOC) emissions was a rare trend observed in only three out of 20 (i.e.,15%) of the sample firms. In addition, all these

companies published data about VOC emissions, with respect to unit production, and without respect to net revenue.

VOC emissions with respect to unit production. As noted above, only three sample companies published data about VOC emissions/unit production, of which two followed the mixed trend presented in Figure 21.

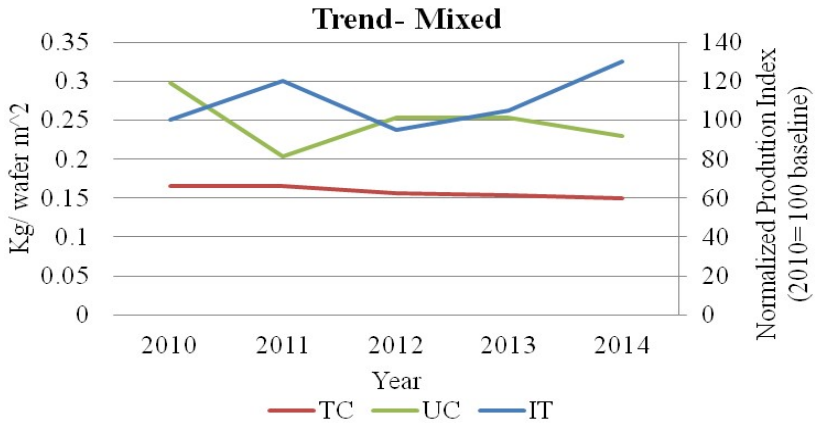

Figure 21. VOC emissions/ unit production (Source: Data extracted from 2010- 2014 sustainability reports of UC, TC and IT)

UC and IT were the two companies that followed the mixed trend. The only logical explanation for this trend could be the mixed trend of absolute VOC emissions for 2010-2014. Since hardly any data about VOC emissions was available, a deeper insight of this trend was not possible.

Nitrogen oxides (NOx). Data analysis of the sample found that only two out of 20 (i.e., 10%) of the sample companies published normalized data about NO_x emissions per unit product. There was no common trend observed among these companies, because one increased while the other decreased per unit NO_x emissions. In contrast, this mixed trend of absolute values of NO_x emissions over 2010-14 decreased in five out of six sample companies that published this data.

The environmental data about resource use and emissions either increased, decreased, or followed a mixed trend over 2010-2014. The next section illustrates each sample company's approach to ecological responsibility. The semiconductor industry is challenged by the use of toxic chemicals, and these chemicals may sometimes enter nearby aquatic bodies through wastewater, leading to increased eco-toxicity of aquatic ecosystems (Villard et al., 2015).

Ecological Responsibility. The analyzed sustainability reports had scarce information about biodiversity. Only three out of 20 (i.e., 15%) of the sample companies conducted a biodiversity assessment of the nearby area, and found that none of their facilities were located near protected areas or had IUCN listed species. Only 20% of the sample companies initiated local conservation practices, such as on-site green gardens, natural ponds, butterfly gardens, and protection of indigenous frogs. Planting trees was the most common way of demonstrating a company's ecological responsibility. The employees from nearly 50% of the sample companies volunteered in tree plantation drives. Employees were the key participants in most local habitat conservation project activities. In addition, 25% of companies invested and volunteered in local watershed management projects, such as riverbank stabilization, wetland conservation, and riverbank cleanups. MR and RN were the two sample companies that restored natural forest-like habitats at some of their facilities in order to attract native fauna. Similarly, embarking on the concept of eco-design, MR, a sample company, also constructed a fish pond that thrived in the facility's treated wastewater.

According to a report by the CERES (2009), eleven out of 14 top semiconductor manufacturers globally are located in water-scarce regions of Asia Pacific. This situation highlights the need for projects to improve groundwater recharge. Although semiconductor companies use a mix of ground water and surface water at different percentages, reinvigorating the water table would definitely prove to be beneficial for the company and its surrounding ecology. MR was the only company from the sample which prioritized biodiversity conservation in its sustainability approach. In short, it can be stated that companies are addressing the importance of biodiversity conservation to some extent, but measures to improve the impact on local biodiversity are still missing. Table 21 summarizes the nature of corporate activities undertaken for ecological preservation in the sample.

Table 21
Ecological responsibility in sample companies (n=20)

Sustainability best practice categories	Activities for ecological conservation by sample companies	No. of companies adopting
Ecological responsibility	Tree plantations	10
	River and coastal cleanups	4
	Watershed management and wetland conservation	3
	On-site biodiversity preservation sites	3
Green building certification	Eco-designed manufacturing facility	1

Stakeholders, such as employees, customers, suppliers, investors, academia, students, government officials, and NGOs are affected by the operations of these companies. The next section describes the activities undertaken by companies for growth and development of their stakeholders and society at large.

Social Trends

Companies invest time, money and workforce on projects that promote well-being in society. According to Lu, Wang, and Lee (2013), social aspects, such as charity and donations, innovative giving, support to education, housing support, and volunteering programs, define the strength of community engagement of a semiconductor company. Based on this understanding, the social initiatives discussed in this section are sub-divided into four categories, which are social investments, diversity in the workplace, employee development programs, and employee volunteering. Such categorization ensures a clear and holistic understanding of this topic. Social disclosures were the second most described category in the analyzed sustainability reports, led by environmental disclosures and followed by economic disclosures. Nearly 90% of the data about social activities was qualitative in nature, showcased as narration and pictorial representations.

Social investments and charity donations. Most companies from the sample had subsidiary organizations or philanthropic foundations that implemented social activities on behalf of the company. Over 2010-2014, eight out of 20 (i.e., 40%) of the sample companies published data about social investments, and interestingly more than half of these companies increased their financial support for social causes over the years. Some companies encouraged their employees to participate in food donation drives, while some invested and donated to medical causes, such as leukemia and breast cancer prevention. Companies also made noteworthy investments in social causes, such as:

- Women education and empowerment

- Construction of neighborhood recreational and sports facilities
- Museums and fine arts
- Support to local cultural events

Most of the sample companies proactively invested in educational institutions, such as universities and schools to promote Science, Technology, Engineering, and Mathematics (STEM) fields. Nearly 55% of the sample companies actively collaborated with local and global universities to encourage students to engage with semiconductor technology careers. Similarly, nine out of 20 (i.e., 45%) companies supported programs for K-12 students. The majority of the sampled companies also sponsored robotic competitions, electric car competitions, quizzes, and educational fairs for students. SC was the only company from the sample which established a fully fledged K-12 school to impart quality education in the local society. In addition, talented budding undergraduate and graduate students were often encouraged by offering educational scholarships, hands-on internships, and co-ops.

In addition to educational collaborations, most companies were actively invested with providing disaster relief during earthquakes, floods, and hurricanes. All Taiwanese companies from the sample provided financial support or volunteered to help victims of the 2014 Kaohsiung gas explosion in Taiwan. Other companies supported various rehabilitation activities and aided relief efforts during the 2011 earthquake in Japan, superstorm Sandy in 2012, typhoon Haiyan in 2013, and the 2014 floods in south-eastern Europe.

Diversity at workplace. Factors such as age, gender, physical ability, cultural background, sexual orientation, race, and religion account for the diversity of workforces (Saxena, 2014). Every company from the sample described the heterogeneity of its workforce with respect to geographical locations, job titles, and company board constitution. Epstein and Roy (2001) mention that employment of women and minorities usually increases employee satisfaction, along with customer growth and retention in a company, which ultimately affects the company's profitability. On the contrary, the nature of semiconductor manufacturing is stigmatized as a male-centric industry since its inception (UN CSR report, 2014). An investment in recruitment and retention of female employees was cited as a top priority by at least 50% of the sampled companies. In the sample, the average percentage of females in each company was 40%, but AS was the only company which consisted of 51% female staff. The dynamics of the industry are gradually changing as more women are appointed to managerial, executive, and board positions. Additionally, each company sampled had well-defined leave plans for maternal-paternal, caregivers, and childcare. Similarly, five out of 20 (i.e., 25%) of the sample companies increased the hiring of individuals with disabilities from 2010-2014. The employment and involvement of minorities and seniors, as employees and suppliers, was also an emerging trend in the sample.

Employee development and volunteering. Stakeholders of a company are employees, customers, community members, government officials, suppliers, media, shareholders, investors, students, and collaborators (SH Sustainability report, 2015). The sustainability reports and the interviews conducted with sustainability officials of

companies consistently highlighted that employees were the most significant stakeholder group in any company. The interviews also restated that investors and employees were the primary audiences for their sustainability reports. There are two quotes extracted from the interviews that exemplify this claim. Corporate Responsibility Manager at ST, (personal communication, August 24, 2015) mentioned,

> "First are employees. We want the employees to know about our programs. We are also proud of our results and we want to do better. We want to share the results with the employees."

Similarly, CSR Communications Manager at IT, (personal communication, August 14, 2015) expressed,

> "Our employees are our secondary target. We want them (employees) to be aware of the great things that we do and they are proud of working here."

Companies are increasingly investing in initiatives that promote career and personal development of their employees. In addition, some best practices such as fair wages, human rights policies, and EHS policies are identified to be vital for employee development and well-being. Similarly, engaging in employee and customer surveys provides feedback about the quality of service provided to customers and helps identify concerns raised by employees. Every company from the sample engaged in career development of its employees through tuition reimbursement, seminars, and e-learning courses. It was observed that six out of 20 (i.e., 30%) of the sample companies increased their spending on employee training over 2010-2014. In contrast to this fact, the number of hours of training per employee followed a mixed trend. About 50% of the companies

recognized and motivated their employees through awards. In addition, the managers at five out of 20 (i.e., 25%) sample companies provided regular career guidance and feedback to their employees.

Secondly, companies support different social causes and motivate employees to participate in these activities. Each employee perceives the company's support of these causes differently; where a few believe that such participation enhances job-related skills, networking, and social behavior, some consider it to be a marketing strategy to lure new employees and customers (Peterson, 2004; Gatignon-Turnau and Mignonac, 2015). Based on this outlook, it is uncertain whether the sampled companies were truly interested in these volunteering initiatives and employee development or if this engagement is more to improve public relations.

Thirdly, companies are diligent about the health and safety of their employees. Most sampled companies held regular health checkups and had 24-hour on-site medical assistance available to all employees. Some companies also had clinics for smoking cessation, obesity, and mental health. OHSAS incidence rates and severity rates have decreased over 2010-2014 and were much lower than the national average of the countries in which the sample companies operated.

Finally, every company in the sample had zero tolerance to sexual harassment, discrimination, forced labor, and child labor. The conflict-free minerals policy for responsible sourcing of minerals such as tantalum, gold, tin, and tungsten was another best practice that was proactively adopted by all sampled companies. IT was the only

company from the sample that produced semiconductor products using all four of these minerals sourced from 100% conflict-free regions.

Summary

This research initially found three trends in the environmental and social parameters of the sample companies. The increasing and decreasing trends are quite self-explanatory. The mixed trend is a combination of increasing or decreasing values of the parameter of interest. However, one pattern within the mixed trend merits further explanation. If, over the five-year period, the values for the parameter increased during the initial three years, then decreased and stabilized during the remaining two years, this pattern is categorized as the "new normal." These stabilized values may serve as a baseline for the company to further improve their resource management practices over the years. The new normal pattern is a desirable trend that may have resulted due to the adoption of some in-house sustainability measures or projects. Subsequently, based on the introduction of the new normal pattern, the sample companies' social and environmental parameters follow four trend-increases, decrease, new normal, and mixed.

Table 22 represents the four different trends observed in the sample. The environmental parameters depicting resource consumption and emissions that follow a decreasing trend or new normal pattern is a desirable or improving trend. Similarly, in a social context, an increase trend indicates more investments and donations which is also a desirable or an improving trait. None of the social data followed the 'new normal' trend. Thus, for ease of understanding, Table 22 indicates an improvement of both environmental and social parameters is denoted by ↑ sign. In the environmental context,

trends such as the new normal and decrease in resource use and emissions are depicted by the ↑ sign. In the social context, an increasing or improving trend is denoted by the ↑ sign. The mixed trend is represented by the ↔ sign.

In contrast, an increasing pattern of environmental resource use and emissions is considered unfavorable for the environment and is regarded as undesirable or showing no improvement. Thus, these trends are represented by the ↓ sign in Table 22. Similarly, social performance, a trend towards fewer investments and volunteering is considered undesirable or no improvement, and thus is also denoted as ↓. The calculations that resulted into the social trend in the Table 22 are appended in Appendix G of the report.

Table 22
Tabulation of environmental and social trends observed in sample (n=20)

Company name	Electricity use/ net rev	Electricity use/ unit prod	Natural gas usage/ unit prod	Total waste generation/ net rev	Total waste generation / unit prod	Haz. Waste prod. /unit prod	Non- haz. waste prod/ unit prod	Total water consumption/ net rev	Total water consumption/ unit prod	Wastewater prod/ unit prod	Total GHG emissions/ net rev	Total GHG emissions/ unit prod	Scope 1 emissions/ unit prod	Scope 2 emissions/ unit prod	VOC emissions/ unit prod	NOx/unit prod	Social performance	Total positive or new normal (↓ or N)	Total negative (↑)	Net positive
AS	↑							↑	↑		↑	↑					↑	6	0	6
TC	↑	↑	↑						↑	↑				↑	↓		↓	6	1	5
TS		↑			↑				↑				↑				↑	5	0	5
IT		↑				↓	↔		↑			↑			↔	↑	↑	5	1	4
NV		↑	↓		↑				↑			↑						4	1	3
NN					↓				↑	↑		↑					↑	4	1	3
RO				↑							↑						↑	3	0	3
SC									↑			↑					↑	3	0	3
ST		↑	↓						↑			↑					↑	4	1	3
TK		↑															↑	2	0	2
MR																	↑	1	0	1
IN																	↑	1	0	1
FS																	↑	1	0	1
SO																		0	0	0
UC		↓	↑		↑	↓			↓	↓			↑	↑	↔		↑	4	4	0
RN																		0	0	0
UN	↑							↓			↓						↑	2	2	0
AD		↓				↓	↔		↓				↑				↑	3	3	0
GF		↓				↓	↔		↓			↑					↑	3	3	0
SH		↓	↓							↓			↓	↓		↑	↑	2	5	-3

Note. ↑ indicates improvement, ↓ indicates decline, ↔ indicates mixed trend, and blank indicates no data available

In the Table 22, decrease in environmental parameters, new normal and increase in social contributions were highly desirable for this analysis. Thus, for every company, the total number of parameters with ↑ sign are subtracted from the number of parameters with ↓ to calculate the net positivity or improvements over 2010-2014. Table 22 presents list of companies arranged in descending order, based on these values. Then, companies were segregated as top performers and bottom performers based on the number of net positive points. All the companies that had positive scores for net positivity fell into the high performing group while those which received zero or a negative score comprised the low performing group based on the social and environmental data trends assessed previously. Table 23 distinguishes these high performing and low performing companies.

Table 23
List of companies based on net positivity values of sustainability parameters (n=20)

No	Higher performers	No	Low performers
1.	AS	1.	SO
2.	TC	2.	UC
3.	TS	3.	RN
4.	IT	4.	UN
		5.	AD
		6.	GF
		7.	SH

The total electricity consumption and total water consumption, scope 2 emissions, and scope 2 emissions when normalized to unit production, decreased over 2010-2014. Similarly, normalized values with respect to net revenue for total electricity, total solid waste, and total GHG emissions followed the same trend over the same timeframe. On the contrary, normalized values for waste water consumption and hazardous waste production with respect to unit production increased steadily from 2010-2014. On the contrary, normalized values with respect to unit production for parameters, such as VOC emissions, non-hazardous waste production, total solid waste generation and total GHG emissions, followed a mixed trend. The mixed trend

followed by normalized total solid waste generation and total GHG emissions, with respect to unit production, demonstrated an interesting pattern known as the new normal. The new normal establishes a new baseline/benchmark for the companies to target greater reduction of emissions and resource use. Some notable factors that may have resulted into the establishment of a new normal could be (1) adoption of energy saving projects, (2) change of manufacturing capacity and processes, and (3) stringent regulations and laws related to GHG emissions and waste segregation. The new normal is established based on the available data assessed for this study, and thus the new pattern warrants further investigation. In the other parameters that followed a mixed trend, no such distinct pattern was observed.

Some information about ecological responsibility was described by every company from the sample, and tree planting was the only activity undertaken by the majority of the companies. A marginal number of companies were interested in their ecological responsibilities, and thus adopted certain state of the art techniques to bridge the gap between nature and economic development.

In contrast, most companies from the sample had independent charitable foundations which supported philanthropic activities in the fields of sports, education, disaster relief, fine art, and culture. Educational collaborations were highly sought by most of the sample companies to increase interest in STEM careers. Companies also believed that employees were the building blocks of the company and invested widely in programs that targeted employee wellness and development. Each report contained descriptions and photographs of employee volunteering activities, but researchers, such as Gatignon-Turnau and Mignonac (2015) and Peterson (2004), have questioned the intentions of companies due to such type of reporting.

Based on the data in the sample companies' sustainability reports, the next section investigates the relationship between size of the company and completeness of sustainability reports.

Relationship between Total Sustainability Disclosure Score and Company Size

Past studies have investigated the relationship between sustainability disclosures and company size (Gomes et al., 2015; Horisch et al., 2014). Based on these studies, the company size of the sample companies can be determined using two parameters: number of employees and net revenue (Lu, Cui, and Le, 2013). The annual net revenue of the sample companies ranged from $0.21to $55.9 billion, and the number of employees varied from 1,269 to 107,600. Since the top and bottom scorers with respect to the total sustainability scores represent two polar cases of sustainability data disclosures, these two groups are used in this analysis. As mentioned above, the two groups each consist of five companies.

Table 24
Analysis of relationship between company size and total score scores

Group	Company name	Total disclosure score (points)	Net revenue in USD billion	Number of employees	Average annual net revenue in USD billion	Average number of employees
Top scorers	TS	91.2	13.0	3,496	18.3	39,782
	IT	92.4	55.9	107,600		
	ST	92.9	7.4	43,600		
	SH	93.9	14.9	26,903		
	UC	96.6	0.37	17,310		
Bottom scorers	FS	48.4	4.6	17,300	2.7	25,918
	GF	52.2	NA	13,000		
	SC	61.1	1.9	10,446		
	RO	66.4	3.0	20,843		
	AS	66.6	1.2	68,000		

Table 24 highlights that the average net revenue of group consisting of bottom scoring companies with respect to the total disclosure scores is $2.7 billion, while the average revenue of the top scoring group is almost seven times more than the bottom scoring group. Thus,

companies with higher revenue have a higher disclosure score and vice versa. Even though the causation relationship between net revenue and disclosure quality cannot be definitively determined from the available data, there is definitely a positive association between net revenue and completeness of sustainability reports. A possible explanation to higher revenue in these firms could be customer loyalty, competitive advantage, and better access to capital (BCCCC and Ernst and Young, 2013; Lu et al., 2013). The findings of this study are consistent with the observations of Plumlee, Brown, Hayes, and Scott Marshall (2010) who noted that higher transparency resulted into greater cash flow.

The number of company employees is also another way to describe company size. Transparency through data published in sustainability reports boosts employee retention and hiring (BCCCC and Ernst and Young, 2013). Based on this premise it can be hypothesized that the greater number of employees corresponds to higher total sustainability disclosure score. Table 24 indicates that the average number of employees in the top-scoring group is higher than the average number of employees in the bottom-scoring group with respect to total disclosure scores. In general, the investigation found a positive relationship between the number of employees and completeness of sustainability report based on the total disclosure score. But the sustainability reports of two sample companies—AS and TS—were exceptional cases among the sample. AS, a sample company with the third largest employee population (68,000) in the sample, discloses less information in its sustainability report and hence constitutes the bottom-scoring group. On the contrary, TS, another sample company which has the third smallest employee base (3,496) among the sample publishes reports that are rich in sustainability data. In addition to these findings, the interviews with the sustainability managers of select sample

companies indicated that the information in the sustainability reports is published to educate the employees about the outstanding initiatives undertaken by the company.

Related research indicates that large companies have better sustainability reporting as compared to small or medium sized companies (Adams, Hills, and Roberts, 1998; Herbohn, 2014; Horisch et al., 2014; Morhardt, 2010; Patten, 1991). In general, the findings of this study are consistent with the findings of these researchers. Even though a positive relationship between completeness of sustainability reporting and company size based on net revenue and total number of employees is noted, the causation between the two factors is still unclear. The sustainability reports of larger companies usually contain complete sustainability data due to the availability of more workforce, financial capital, and new technologies, as compared to small- and medium-sized companies.

This section provided deep understanding about the company size and its relationship with the quality of disclosures in the sustainability reports. The next section examines the relationship between the two most important aspects of this research study: sustainability performance and completeness of sustainability disclosures.

Relationship between Report Completeness and Sustainability Performance

One of the main objectives of this research study is to understand the overall sustainability practices of the semiconductor industry, based on three factors: (1) sustainability performance based on adoption of best practices, (2) sustainability performance based on social and environmental data trends, and (3) completeness of sustainability disclosures in reports. The previous analysis highlighted the different methodologies adopted to identify any discernible trends in 20 sample companies. Different terminologies were used to describe top and bottom-performing companies across a wide range of evaluation parameters. For example, the terms

"progressive" and "developing" companies were used for understanding sustainability performance based on the adoption of best practices; the terms "high" and "low" were used for understanding sustainability performance based on normalized data trends in companies; and the terms "top" and "bottom" were used to describe sustainability disclosure practices. Although these terminologies differ, the underlying meaning of each term in the top group (progressive, top, and high) and bottom group (developing, bottom, and low) is the same. Based on previous findings, Table 25 compiles the key findings of the three investigations conducted previously.

Table 25
Comparison of sustainability disclosures and sustainability performance in the sample

	Name of company	Sustainability disclosure		Sustainability performance (normalized data trends)		Sustainability performance (best practices)	
		Top scorer	Bottom scorer	High performer	Low performer	Progressive companies	Developing companies
1.	UC	Y			Y	Y	
2.	TS	Y		Y			
3.	SH	Y			Y	Y	
4.	IT	Y		Y		Y	
5.	ST	Y					
6.	GF		Y		Y		
7.	SC		Y				Y
8.	RO		Y				
9.	FS		Y				
10.	AS		Y	Y			

Note. Y indicates that the company was a constituent of the group. Blank indicates no data.
Yellow block indicates high disclosers and high performers
Green block indicates low disclosers and low performers
Blue block indicates low disclosers and high performers

Based on Table 25, IT is the only company from the sample that is not only a top scorer in sustainability disclosures, but also a high adopter of sustainability best practices, and a high performer based on sustainability performance trends. These characteristics make IT the best company in the sample with respect to report completeness, best practice adoption, and sustainability performance.

Table 25 indicates that four out of five companies from the top-disclosing group had a positive association between sustainability performance and report completeness, and vice versa. Even though a positive association between the two aspects is noted, based on the available data, it is difficult to state the causation between the two factors. In contrast, among the five bottom-disclosing companies, no significant relationship between sustainability disclosures and sustainability performance was observed, as two out of five companies had a positive relationship between the two parameters and one had a negative association.

Generally, if a company discloses fewer sustainability data in its sustainability reports, it does not necessarily mean that its sustainability performance will also be low. Since this study provides only a snapshot of the current sustainability reporting practices and sustainability performance in the sample companies, social and environmental performance and completeness of sustainability reporting are positively related in the top disclosing group, but not necessarily in the bottom-disclosing group of companies.

In addition, no significant relationship was observed between the adoption of sustainability best practices and sustainability performance trends. The adoption of best practices may or may not guarantee improvement in the socio-environmental data trends. For example, in sample companies NN and NV, the low adoption of sustainability practices has not hindered progress in socio-environmental data. Similarly, AD and SH, two sample companies, have adopted a high number of sustainability best practices, but the actual sustainability performance data contradicts this observation. A possible explanation for the relationship between the adoption of best practices and its relationship with sustainability trends could be the slow maturity of the processes. It is expected that the future data investigation may show improvements in sustainability performance due to the maturity of present practices.

Discussion and Conclusion

Comparison of Past and Present Findings

RQ 1. Daub (2007) mentioned that the primary goal of every company is usually profit maximization, and often social and environmental considerations are neglected during this quest. The survey results partially contradicted this belief, because ethical factors and socio-environmental well-being of stakeholders were cited as key motivations by all the 10 surveyed companies. At the same time, respondents said that their companies benefitted competitively by engaging and reporting on their sustainability initiatives. The survey participants also agreed that sustainability reporting also boosted the shareholder value and public image of the company.

Stakeholders play an important role in the success of a corporation. A survey conducted by Boston College Center for Corporate Citizenship and Ernst and Young (2013) found that seeking transparency with the stakeholders is the key driver behind publishing sustainability reports among the manufacturing sector. Most of the interview participants agreed that employees were the company's biggest stakeholder base, as far as the reporting was concerned. However, the surveys highlighted that companies were not obligated to publish sustainability reports due to employee pressures. In fact, the sustainability reports were published to inform employees about the outstanding social and environmental initiatives of the company. The pressures from other stakeholders, such as government agencies and customers, were also not considered key motivations for publishing reports by any of the companies surveyed. Interviews and survey data reiterated the idea that the companies publish sustainability reporting as a way to maintain an ongoing dialogue between stakeholders and the company.

The surveys administered for this research exemplified that the companies saved costs by adopting sustainability practices, rather than just reporting these measures publicly. Companies

mentioned that projects for GHG reduction, waste recycling and segregation, energy management and water-use reduction led to considerable cost savings over the years. As a result, this research indicates that cost saving is not related to publicly reporting on sustainability. This finding thus contradicts the observation by Kolk (2002 and 2003), who noted cost reduction and efficiency were greater motivators for sustainability reporting than external factors, such as government regulations or incentives.

RQ 2. The vast variability in the sustainability disclosure scores calculated using the modified sustainability matrix highlights that the coverage and depth of data on social and environmental impacts differ greatly in every company's sustainability report. This finding is concurrent with the IRI (2010) study which found that sustainability disclosure practices are highly company-specific. The sustainability reports of companies that scored low in the total sustainability disclosure scores were deficient in at least one (and sometimes two) of the important reporting categories: environmental and social. These observations contradict the findings of Daub (2007) who found that some company reports scored poorly in the total or overall score but excelled in specific performance categories (environmental, social, and fiscal). In addition, the approach to environmental data representation was far more advanced as compared to information on social initiatives.

RQ 3. Docekalová and Kocmanová, (2015) mention that corporate success of a company must be measured not only by the economic profitability, but also by its sustainability performance, and accountability. Sustainability performance of the 20 sample companies was judged based on the adoption of sustainability best practices and trends within normalized and absolute data related to social and environmental aspects. Usually, progressive companies from the sample were at the forefront in adopting sustainability best practices. However, results of

these efforts were not reflected directly in the trend analysis conducted for normalized data about GHG emissions, water use, waste generation, electricity consumption, and energy use. A possible explanation for this finding could be the slow maturity of sustainability processes, where the results might take several years to be realized. IT, a sample company, mentioned that past trends of social and environmental aspects provide an overview of company approaches toward sustainability, but they may not guarantee future success. Further study on this aspect using a larger sample size and larger timeframe could explain the progress of present social and environmental practices.

Biodiversity was the most underrepresented component in the sustainability reports. Very few companies demonstrated an explicit interest in preserving local ecological diversity. Most sample firms perceived tree planting as the best way to show their commitment to biodiversity. A possible explanation for this lack of engagement could be a limited understanding about biodiversity among stakeholders and the amount of time required to conduct biodiversity assessments and projects. Similarly, in the social context, employee volunteering and donations to charitable organizations was the most dominant trend in the sampled companies. Information presented through photographs of employee volunteering was very common in nearly 50% of the sampled reports. Gatignon-Turnau and Mignonac (2015) and Peterson (2004) have argued that such portrayal of data about social activism is the most widely adopted way to attract new employees and may sometimes be deceptive. Nearly 90% of the sampled companies invested in activities that encouraged students to take up education and careers in STEM disciplines.

As mentioned previously, description of environmental projects in sustainability reports was more developed as compared to social initiatives. In addition, the adoption rate of environmental projects for GHG reductions and waste production was higher as compared to the adoption of

projects for water reduction, reuse, and recycling. Nevertheless, every sample company adopted several energy-related initiatives that benefitted the company in two ways: cost savings through decreased energy usage and reduction in scope 1 and scope 2 GHG emissions. The cost savings from these energy projects were very well documented in the sustainability reports of sample companies. A possible reason for greater representation of this data could be easier quantification of savings from energy and water projects as compared to other initiatives (Director, Sustainability Stakeholder Relations at TS, personal communication, August 18, 2015). In addition, the sample companies also saved costs through waste segregation and resource extraction.

Stages of sustainability adoption. The typical stages of sustainability adoption in a company as described by Brusman (2009) (Figure 2) is a linear process. Based on the analysis of the sustainability reports in this research, companies do not necessarily follow the five stages in the same order. For example, TK, a sample company, has prioritized product sustainability over the other traditional environmental aspects, such as waste production, GHG emissions, energy usage, and water consumption. Similarly, SC, a sample company, ranks employee well-being and benefits over projects that would reduce the company's operational impacts on the environment. Thus, every sampled company had varying approaches to sustainability and did not necessarily follow the linear progression as described by Brusman (2009) for reducing their impacts on the environment and society at large. Figure 22 describes an example of the sustainability adoption stages as observed in the sample companies.

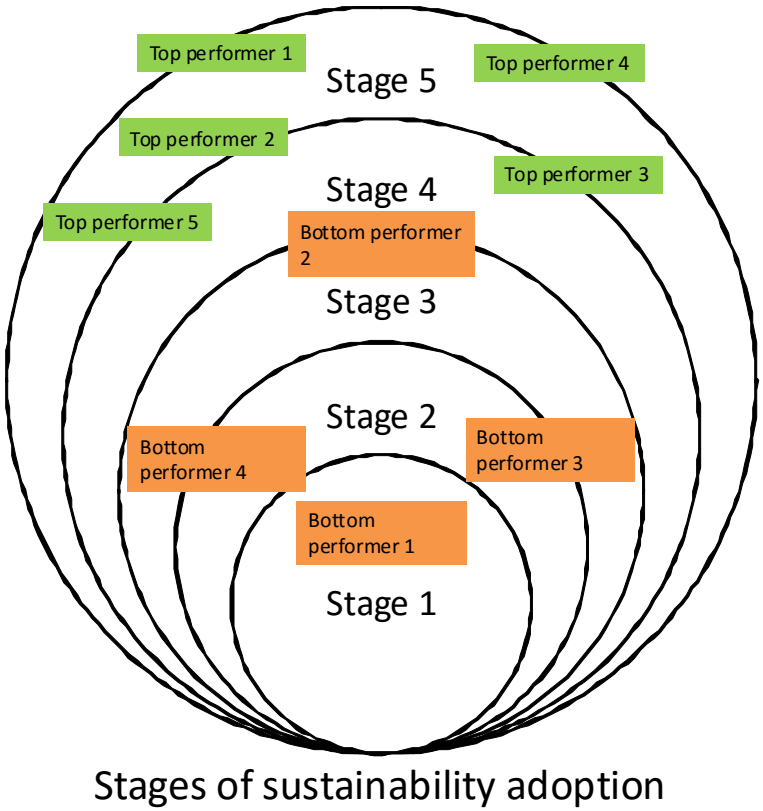

Figure 22. Example of observed sustainability adoption sequence in the sample companies (for representative purposes only)

Figure 22 represents that the stages of sustainability adoption are not necessarily linear in the sample companies but independent of each other. For example, a company may target product sustainability right from the early stage of sustainability adoption and may leapfrog the initial two stages described by Brusman (2009).

Company size and report completeness. Researchers, such as Herbohn (2014) and Horisch et al. (2014) mention that larger companies disclose more information because they are more exposed to stakeholder pressures. In general, the findings of this research are consistent with the findings of these two researchers, as we observed a positive relationship between completeness of sustainability reports and company size based on annual net revenue and total number of employees. Interestingly, UC is the only company from the sample which contradicts this finding, because the company has the second lowest annual net revenue in the sample, yet

receives the highest total disclosure scores. Similarly, TS and AS, two sample companies, were the notable exceptions that did not demonstrate a positive relationship between sustainability data completeness and company size based on the number of employees. The two sample companies, TS and AS, had the third smallest and third largest employee population respectively among the 20 sample companies. In spite of this fact, TS constituted the top-disclosure group while AS fell under the bottom-disclosure group. This research also found that reporting about environmental parameters was more developed, compared to social categories with regard to both qualitative and quantitative information.

Relationship between report completeness and sustainability performance. This research study also establishes a positive relationship between sustainability data completeness and the sustainability performance, based on at least one of the two categories: adoption of sustainability best practices or trends in social and environmental performance data. These findings are concurrent with the findings of Al-Tawaijri et al. (2004), Clarkson (2008), Clarkson et al. (2011), and Herbohn (2014), who found a positive relationship between sustainability disclosures and environmental performance. Thus, the findings of this study contradict the findings of Deegan and Gordon (1996), Deegan and Rankin (1996), and Patten (2002), who found a negative relationship between sustainability disclosures and environmental performance. Although this research found a positive relationship between the two aspects of sustainability reporting and performance, the approach to sustainability was highly organization specific in the sample.

Extensive growth patterns were more common in the environmental data than intensive growth patterns, which means the quantity of input and quantity of output have a direct proportion, e.g., increase in net income achieved through more input of water, electricity, and raw material. On the contrary, based on the finite availability of resources and growing

environmental degradation, it is expected that companies follow intensive growth patterns where same input results into greater output, e.g., same quantity of raw material leads to more quantity of product. These extensive growth patterns suggest that sustainability is yet to be institutionalized into the core principles of the sample companies.

Companies responded positively to laws, such as EU product restrictions (REACH, RoHS, and ELV[6]), conflict mineral policies, and human rights policies, because these are mandated nationally and internationally. Most companies are adopting sustainability reporting voluntarily. However, mandating the practice of sustainability reporting would definitely boost the adoption rate as observed from some example such as EU product restrictions and human rights policies. Companies would definitely welcome some kind of mandate on sustainability reporting in the near future. The findings of this study mirror the observations of the survey conducted by Ernst and Young (2014), where 69% of the sustainability professionals mentioned that some national sustainability reporting compulsion would benefit organizations and governments. In addition, about 35% of these survey participants also expected such a rule to take effect in the next two to five years (Ernst and Young, 2014). In addition, rewarding companies that provide a holistic understanding of the sustainability initiatives through their sustainability reports can definitely motivate publication of high-quality reports. Presently, companies that disclose complete information on sustainability in their reports are only indirectly rewarded by supplementary advantages such as competitive edge and stakeholder trust (Daub, 2007). Several local and national organizations confer awards on companies based on their sustainability innovations and projects. These awards to some extent motivate companies to adopt sustainability practices and publicize their initiatives publicly.

[6] End of Life Vehicle (ELV) is the program initiated by the EU to ensure eco-friendly disposal of motor vehicles after the end of their useful life (European Commissions, 2016)

Strengths of the Study

This research modified the sustainability matrix developed by Daub (2007), such that environmental and social disclosures had relatively higher weight, as compared to traditional economic and other strategic disclosures. Daub (2007) studied the quality of disclosure in the reports published by multiple industries using the sustainability matrix. Different industries have different resource uses and externalities, thus, the modified sustainability matrix was applied to a singular industry to ensure a fair comparison. Such a sustainability matrix framework has not been used by any previous studies. In addition, it is the first study about sustainability reporting for the semiconductor manufacturing industry which involves both qualitative and quantitative methods.

Similarly, the timeframe for the normalized data analysis (2010-2014) provides a snapshot of sustainability performance trends in light of the economic recovery period after the 2009 global financial crisis. In most of the 20 sample companies, the trends in socio-environmental data represented unfavorable conditions during 2010-2012 i.e., immediately after the downturn and improved during the later three years. This quantitative trends analysis ensures a fair comparison of companies based on a common matrix.

In addition, the best practices related to manufacturing processes of the semiconductor industry have not been investigated in any previous studies. This one-of-its kind study compiled a list of 28 best practices about social and environmental topics specific to this industry based on the past literature. In addition, the survey and interviews support the observations of the study that assesses sustainability reporting completeness, as well as social and environmental performance of the sample companies. The interviews provide a deeper understanding about the

flow of sustainability practices in a semiconductor company beyond the descriptions in sustainability reports, and they allow for identification of trends across companies.

Areas of Future Research

Most of the normalized environmental parameters followed a decreasing trend, which is a positive indication that companies are taking actions to reduce their impacts on the environment. In this study, two out of the four environmental parameters that followed mixed trend over 2010-2014, also demonstrated a novel pattern previously described as the "new normal " The new normal could indicate a progressive trend for companies and could be used as a baseline to target greater reductions of resource use and emission releases in the future. This new pattern warrants further investigation using a larger sample size and larger time period.

This study provides a starting point for future investigations on sustainability best practices and their association with sustainability performance based on social and environmental trends. Based on the available data, it was found that these two criteria were not directly related (Table 25). A further examination on this subject will provide a greater understanding of whether adoption of sustainability practices impacts the company's socio-environmental performance. In general, this research found a positive relationship between sustainability report completeness and sustainability performance in the top-disclosing group of companies, but the same association was not observed in the bottom-disclosing group of companies. Generally, if a company discloses fewer sustainability data in its sustainability reports, it does not necessarily mean that its sustainability performance will also be low. Herbohn, Walker, and Loo (2014) found that companies with good sustainability performance usually disclose complete data in the reports and this finding mirrors the assumptions of the stakeholder theory. Even though we expect that firms which are proactive in addressing the sustainability aspects of their

organization will disclose better information in the sustainability reports, the available data restricts establishment of any such causation. Hence, the causation between completeness of sustainability data and sustainability performance warrants further investigation.

Conclusion

In this research, the top companies were usually integrated chip manufacturers that produced complete reports, adopted several sustainability best practices simultaneously, and also outperformed with respect to social and environmental trends. The foundries, on the other hand, had no distinct pattern with respect to reporting completeness and sustainability performance. Similarly, as the number of companies selected from each geographical area was not uniform, it would be inaccurate to correlate sustainability performance and report completeness with the geographical locations.

Ethical reasons and concern about the society and environment drive reporting in the sampled semiconductor manufacturers. The sustainability managers also mentioned that reporting does not contribute to cost savings, but adoption of programs related to energy saving, water conservation, and waste minimization definitely save costs. An analysis of completeness and performance parameters highlighted that social initiatives are underdeveloped in comparison to environmental sustainability in the sample semiconductor companies. The number of years into sustainability adoption certainly affected the maturity of sustainability policies in most sampled companies. Sustainability is a very complex subject that lacks concrete performance benchmarks for social and environmental parameters. This absence of a regulatory framework allows the company's top management to decide the priorities of investment in sustainability projects, thus providing a partial explanation for the wide variation in reporting completeness, adoption of best practices, and environmental performance across firms.

Educational support programs for youth and disaster relief for the community were the two most common activities depicting social responsibility in the sample companies. Developing and supporting programs for STEM education shall provide educated workforce to the industry. In addition, financial support and scholarships enable good quality education, which further provides a good standard of living to talented students. The disaster relief initiatives undertaken by the sample semiconductor manufacturers ensure quick recovery of the supply chain along with helping the affected civilians. In addition, Johnson, Connolly, and Carter (2011) in a study of the Fortune 100 companies found that the disaster relief efforts are undertaken by organizations as an ethical responsibility, and employees, customers, and the communities are the common beneficiaries of these activities.

In addition, the majority of the developing companies with respect to the adoption of best practices had incorporated initiatives from a regulatory standpoint. On the contrary, companies from the progressive group adopted several advanced best practices such as product LCAs and water footprints, reducing use of UPW and acquiring green building certifications. Presence of a sustainability champion in the company could be one of the many reasons behind this trend. The interviews conducted for this research highlighted that TS, ST, and IT, which topped with respect to report completeness as well as the sustainability performance, each had a sustainability champion that guided each company's sustainability initiatives and reporting for at least a decade. Since none of the sustainability managers from the bottom performing and bottom disclosing groups were interviewed, the presence of such a sustainability champion is unknown in that group.

The analysis of the historical trends from 2010- 2014 for environmental parameters specific to the semiconductor manufacturing industry is compiled in the Table 26.

Table 26
Trends in normalized data from 2010-2014 in the sample

Trend	Environmental aspect
Decrease	Electricity consumption Total water consumption Wastewater generation Scope 1 GHG emissions Scope 2 GHG emissions
Increase	Electricity consumption Natural gas usage Hazardous waste production
Mixed	Non-hazardous waste production VOC emissions
New normal	Total GHG emissions Total solid waste production

As evident from Table 26, water consumption, wastewater generation, and scope 1 and scope 2 GHG emissions have decreased over time. On the contrary, natural gas usage and hazardous waste production have steadily increased. Electricity consumption, non-hazardous waste production, and VOC emissions do not follow any definite pattern over 2010-2014. The total GHG emissions and total solid waste production data exhibits an interesting trend known as the "new normal." This stabilization in the emissions and resource use could serve as a new baseline for targeting further reductions. Some notable factors that may have resulted into the establishment of a new normal could be (1) adoption of energy saving projects, (2) change of manufacturing capacity and processes, and (3) stringent regulations and laws related to GHG emissions and waste segregation.

Over the past two decades, semiconductor manufacturers have become more aware of their environmental and social responsibilities. Consequently, they have taken substantive action; however, the disclosure of data, as well as performance, varies significantly within and across companies. The majority of the companies studied for this research had incorporated

sustainability initiatives as a response to certain government regulations. Therefore, setting industry specific environmental and social goals by industry consortiums such as EICC, WSC, SIA, etc., may result into constructive efforts for addressing global issues, such as climate change, water scarcity, and resource depletion. Additionally, this research found that the sample companies in this industry focused more on addressing environmental impacts as compared to social aspects of company operations. In the environmental context, programs for reducing GHG emissions, energy usage, and waste production were prioritized as compared to reducing water use. Looking forward, the findings of this research provide support for the idea that more voluntary, systematic, and quantifiable efforts that have companies reporting data in comparable units of measurement are necessary to understand if actual progress is occurring and to ultimately preserve ecosystems and promote social equity.

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Appendices

Appendix A

List of sample semiconductor manufacturing companies

No.	Company name*	Headquarter location	Net revenue in USD billion	No of employees
1.	NV	Hsinchu, Taiwan	0.21	1,269
2.	UC	Hsinchu, Taiwan	0.37	17,310
3.	SO	Chiba, Japan	0.78	1,823
4.	AS	Kaohsiung, Taiwan	1.20	68,000
5.	NN	Taoyuan, Taiwan	1.45	2,495
6.	UN	Taoyuan, Taiwan	1.86	21,327
7.	SC	Shanghai, China	1.97	10,446
8.	AD	Norwood, USA	2.63	9,000
9.	RO	Kyoto, Japan	3.02	20,843
10.	FS	Austin, USA	4.60	17,300
11.	IN	Neubiberg, Germany	4.91	29,800
12.	RN	Tokyo, Japan	6.93	27,200
13.	ST	Geneva, Switzerland	7.40	43,600
14.	MR	Kyoto, Japan	8.68	48,288
15.	TK	Tokyo, Japan	9.01	88,076
16.	TS	Dallas, USA	13.05	3,496
17.	SH	Incheon, South Korea	14.93	26,903
18.	TC	Hsinchu, Taiwan	23.63	43,591
19.	IT	Santa Clara, USA	55.90	107,600
20.	GF	Santa Clara, USA	NA	13,000

*Note. Company names have been abbreviated for confidentiality

Appendix B

Interview guide

Assessment of Motivation and Completeness in Sustainability Reporting

Name:
Company
Address:
Function:
Department:
Contact info:
Telephone no:
Email id:
Date: Day:

1. How would you define Sustainability?
2. Could you briefly describe the structure of [company name]'s sustainability department?
3. Is someone or a single department generally responsible for initiating sustainability measures in the organization?
4. What are the different media used to communicate the company's environmental, economic and societal goals and achievements with the public?
5. What do you think motivates [company name] to report on social and environmental improvements as a standalone sustainability report?
6. What are the different problems that [company name] faces in the preparation of sustainability report?
7. If [company name] publishes standalone sustainability reports, who does the company see as the target audience for these reports?
8. Who prepares the sustainability reports? Is it done in-house or through a third party contractor?

9. In [company name]'s sustainability report, it is observed that a third party has assured the data accuracy. Why do you think is this assurance important?
10. Could you describe in brief the methodology used to gather data from the different units/departments of the company for the preparation of the annual sustainability report? How long does the report development process take?
11. Does [company name] have any incentive or policy for managing suppliers that undertake environmental, economic and societal initiatives?
12. Has any data or analysis from annual sustainability reports ever been used in the decision-making?
13. Do you think innovations in products and supply chain strategies such as (XX) and (YY) have led to any cost saving for [company name]? Can you provide a few examples?
14. To what extent do you think participation in social initiatives affected [company name]'s image?

Appendix C

Survey

Factors that affect sustainability reporting in the semiconductor manufacturing sector

Name:
Company
Function:
Department:
Email id:

Given below are some of the factors that motivate standalone sustainability reporting found from the literature review. What are the different motivations behind undertaking sustainability reporting specific to your organization? Please tick the box below where 5 indicates you strongly agree and 1 indicates you strongly disagree.

No.	Motivating factor	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
		5	4	3	2	1
1.	To increase shareholder value					
2.	To gain competitive advantage					
3.	Cost saving					
4.	Ethical responsibility and accountability					
5.	Care about the Environment and Society					
6.	Pressure from stakeholders					
7.	For building a green image					
8.	Pressure from governmental agencies and regulators					
9.	Employee pressure					
10.	Increased efficiency and waste reduction					
11.	Pressure from clients/customers					

Do you think of any other factors that motivate semiconductor manufacturers to publish standalone sustainability reports?

Appendix D

Consent form

Agreement to participate in research

Responsible investigator-

Swarali Bhat
Graduate student
Department of Environmental studies
San Jose State University

Title of the study-

Silicon Revolution: an assessment of motivation and completeness in sustainability reporting in the semiconductor manufacturing sector

1. You have been asked to participate in a research study investigating the factors that motivate standalone sustainability reporting in the semiconductor manufacturing industry. You will be asked to discuss the factors that make it both easy and difficult for your organization to undertake stand alone sustainability reporting. Finally you will be asked to discuss your opinion about sustainability reporting in the semiconductor manufacturing sector.
2. You will be asked to participate in one semi-structured interview that will take about 60-90 minutes. The interview will be conducted at a location convenient to you and where you will be comfortable in sharing your opinion on the subject.
3. The interview will be conductor via Skype, WebEx or telephone if meeting in person is not possible.
4. The interview will be audio-recorded with your permission.
5. There are no risks anticipated with your participation in the interview. All the data collected in this interview will be 100% confidential and will be used only for academic

purposes. The name of the interviewee and the company will not be disclosed in any findings of this study.

6. There are no direct benefits to the interviewees that participate in the survey. The practice of standalone sustainability reporting is in a nascent stage. Therefore this study will add to the generalizable knowledge about the field of standalone sustainability reporting. A possible indirect benefit of your participation in the study would be that the insights obtained from these interviews may enable development of a sustainability reporting system which is simple and sector specific.
7. No compensation is provided for participation in the interview.
8. You are guaranteed privacy and confidentiality. A coding system will be used to save data for each participant. All the identifying information will be kept in password protected folders on the researcher's laptop. The data gathered during this study will be used for academic purposes only.
9. Your participation in this study is completely voluntary. You can refuse to participate in the entire study or any part of the study without any negative effect on your relations with San Jose State University. You also have the right to skip any question you do not wish to answer. This consent form is not a contract. It is a written explanation of what will happen during the study if you decide to participate. You will not waive any rights if you choose not to participate, and there is no penalty for stopping your participation in the study.
10. For further information about the study, please contact Swarali Bhat at (phone no) or email at Swarali.bhat@sjsu.edu or both. Complaints about the research may be presented to Dr. Rachel O'Malley, Acting Chair, Department of Environmental studies at San Jose

State University at Rachel.omalley@sjsu.edu. For questions about participants' rights or if you feel you have been harmed in any way by your participation in this study, please contact Dr. Pamela Stacks, Associate Vice President of the Office of Research, San Jose State University, at (phone no).

11. Your consent is being given voluntarily. You may refuse to participate in the entire study or any parts of the study. You have the right to answer any question you don't wish to answer. If you participate in the study, you are free to withdraw at any time.
12. The signature of a subject on this consent form indicates agreement to participate in the study. The signature of the researcher on this document indicates agreement to include the above named subject has been fully informed of his/her rights.

_____ _____ _____

Participant's Name (printed) Participant's Signature Date

_____ _____ _____

Investigator's Name (printed) Participant's Signature Date

(Initials)_____I allow the researcher to audio record me as part of the research process.

Signature_____

(Initials)_____I allow the researcher to video record me as part of the research process.

Signature_____ (For interviews via Skype or WebEx only)

(Initials)_____ I do not allow the researcher to audio or video record me as part of the research process.

Appendix E

Example of data collection framework for reporting completeness (Daub, 2007; GRI, 2015)

Category A: Context and Coverage					
No of criteria	Grading scheme	Parameters	Descriptions	Points received	Comments
1	0 to 3	Company profile and report profile	Name of the organization Headquarter location Markets served, types of customers and beneficiaries Total number of employees, operations, net sales/revenue, debt and equity, quantity of prods and services Employees by gender- contract and permanent, employees and supervisors, region Percentage of total employees covered by collective bargaining agreements. Process for defining the report content and aspect boundaries Reporting period Date of most recent previous report (if any) Reporting cycle (such as annual, biennial). Nature of ownership and legal form		
1	0 to 3	CEO statement	Msg by CEO, short and long term sustainability goals, trends, priorities, targets		
1	0 to 3	Corporate vision	how the precautionary approach or principle is addressed by the organization		
1	0 to 3	External business and Sustainable developmen t trends	primary brands, products, and services Number of countries of operation with significance to sustainability aspect Organization's supply chain. Significant changes in organization's size, structure, ownership, or its supply chain		

Appendix F

List of best practices adopted by sample companies

No	Best practices in sustainability	Name of company																			
		IT	AD	UC	SH	IN	TS	TC	AS	UN	MR	ST	RO	GF	RN	FS	TK	NV	NN	SO	SC
1	Long term sustainability goals	■	■		■	■	■	■	■	■			■	■		■					
2	Sustainability strategy and department	■		■	■	■	■	■	■	■	■	■	■		■		■	■	■	■	■
3	Product compliance certification	■	■	■	■	■		■	■	■		■	■	■		■	■		■	■	
4	Risk management system	■		■	■	■	■		■	■	■	■	■	■	■	■		■		■	■
5	Environment Health and Safety policy and department	■	■	■	■	■	■	■		■	■	■	■		■	■	■	■	■	■	
6	Energy efficiency projects	■			■	■	■		■		■	■									■
7	Green building certification	■	■	■			■	■	■					■							■
8	Human rights policy	■	■	■	■	■	■	■		■	■	■	■	■	■	■		■	■	■	
9	Conflict minerals policy	■	■	■	■	■	■	■	■	■	■	■	■	■	■		■			■	■
10	Employee and customer survey		■	■	■		■	■				■			■		■		■	■	
11	Materiality analysis for identification of sustainability KPI		■	■	■	■	■		■	■		■	■					■	■		
12	Climate change and elimination of ODS	■	■	■		■					■	■			■	■					
13	Life cycle assessment	■	■	■	■				■			■					■				
14	Fair wages	■	■	■	■	■	■	■	■	■				■		■			■		■
15	CDP disclosure and carbon-water footprint	■	■	■	■			■						■				■	■		
16	Reusable packaging	■	■								■			■							
17	Reduction and reuse of ultra pure water	■				■		■													
18	Supplier responsibility	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		■			■
19	Green transportation	■	■					■		■	■										
20	Waste reduction projects		■		■	■	■		■		■		■		■	■	■	■	■		

Appendix F

List of best practices adopted by sample companies

No	Best practices in sustainability	Name of company																			
		IT	AD	UC	SH	IN	TS	TC	AS	UN	MR	ST	RO	GF	RN	FS	TK	NV	NN	SO	SC
21	Third party assurance of sustainability report		■	■		■		■	■	■		■									
22	Diversity and inclusion	■				■	■			■					■	■					
23	Water conservation projects	■	■	■	■	■			■		■										■
24	Fines and violations	■		■	■		■	■	■	■	■	■		■		■	■	■			
25	Normal working hours		■										■								
26	Sustainability benchmark certificates	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
27	Facility audits	■		■	■	■				■	■		■		■		■	■		■	
28	Sustainability reporting	■	■	■	■	■		■	■	■			■			■					
Total number of practices adopted		23	21	20	20	20	17	17	17	17	16	16	14	13	13	13	12	12	11	10	10

Note. Green block represents that the best practice was adopted in the company while white block indicates it was absent

Appendix G

Tabulation of social trends in the sample (n=20)

Company name	Social parameters								Total positives (out of 8)	Total negatives (out of 8)	Net positive	Sign
	Social investments and donations	% of disabled employees	% of women	Employee training and development investment	Employee volunteering hours	EHS Incidence rate	EHS Severity rate	Total number of employees				
IN		↑	↑	↑		↑		↑	5	0	5	↑
TK		↑	↑	↑			↑	↑	5	0	5	↑
SH	↑	↑	↑	↑	↓			↑	5	1	4	↑
RO	↑					↑	↑	↑	4	0	4	↑
UC	↑	↑		↑	↑	↓	↑		5	1	4	↑
UN	↑	↓	↑	↑		↑	↓	↑	5	2	3	↑
FS			↑			↑		↑	3	0	3	↑
AS		↑						↑	2	0	2	↑
TS	↑				↑				2	0	2	↑
IT	↓		↓	↑	↑	↑		↑	4	2	2	↑
AD				↑		↑			2	0	2	↑
MR						↑		↑	2	0	2	↑
SC						↑		↑	2	0	2	↑
GF						↑			1	0	1	↑
NN	↓					↑	↑		2	1	1	↑
ST	↓		↑	↓	↑	↑	↑	↓	4	3	1	↑
TC				↓		↓	↓	↑	1	2	-1	↓
NV									0	0	0	NA
RN									0	0	0	NA
SO									0	0	0	NA

Note. The sign ↑ indicates an improvement, ↓ indicates a decline, blank indicates no data available