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The effective practices of mobile phone producers' green supply chain management in reducing GHG emissions

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Abstract

The aim of this study is to identify management practices that effectively reduce greenhouse gas (GHG) emissions with regard to the green supply chain adopted by mobile phone producers. Six cases were surveyed (Apple, Samsung, LG, Huawei, Nokia, and ZTE). The main source of data was sustainability reports, which were retrieved from the Global Reporting Initiative database. A special data analysis technique called rank analysis was adopted. The results revealed that the effective practices to reduce GHG 1 emissions were related to production process and business travel; those that were effective for reducing GHG 2 emissions were related to facilities accreditation and energy saving; and those effective in reducing GHG 3 emissions were related to logistics and customer practices. No effective actions related to the management of relationships with suppliers were identified by this study. Indicative models for the relationship between actions and GHG emissions were developed, as was a value-stream map. The previous studies reporting the effective practices in other industries reported results for reducing GHG 1 or GHG 3, or overall GHG emissions, without discriminating among the actions taken to reduce such emissions, although some limited actions were reported. This study describes the effective practices along the whole supply chain—both upstream and downstream—and it also lists the actions related to addressing all the emissions, whether GHG 1, 2, or 3.

KEYWORDS
effective practices, GHG emissions, green, mobile phone, supply chain

1 | INTRODUCTION

The Paris Agreement adopted in 2015 set the specific intentions of holding global warming to well below 2 degrees Celsius (°C) under preindustrial levels, and of trying to limit warming to 1.5°C. The successful Paris Agreement has generated and incentivized action on the appropriate scale by both governments and the private sector. Global greenhouse gas (GHG) emissions in 2020 are likely to be at the high end of the acceptable range of these targets. This increases the challenge of meeting the necessary 2030 emission goals. Accordingly, more effort should be made to reduce GHG emissions as recommended by the Paris Agreement (United Nations [UN] Environment, 2017).

The Information and Communication Industry (ICT) has received little attention as a significant contributor to GHG emissions, despite the increase in its contribution from 1% to 1.6% of the worldwide GHG emissions in 2007, rising to 14% in 2016. By 2040, it will exceed this figure. The carbon footprint of smartphones alone will outstrip the individual contribution of desktops, laptops, and displays by 2020 (Belkhir & Elmeligi, 2018). Smartphones represent a fast-growing segment of

ICT (Wilson, 2018). About 1.9 billion of them were sold in 2017, and the number is expected to reach 6.1 billion by 2020, enough for 70% of the global population (Jardim, 2017).

The use phase of smartphones has become increasingly energy efficient over the years, which has helped to reduce GHG emissions, but the manufacturing phase remains hopelessly reliant on fossil fuels. The entire lifecycle of the iPhone 6s emitted about 95 kg of CO_2, 85% of which occurred in the manufacturing stage (Suckling & Lee, 2015). The projected sales of 80 million of the iPhone 6s are expected to generate a total annual carbon footprint of 6,460 kilotons of CO_2, which is greater than the emissions of 770,000 people and all the business of the London boroughs of Westminster, Lambeth, and Camden put together (Good Electronics, 2015). In addition, building an iPhone 7 Plus creates roughly 10% more CO_2 emissions than an iPhone 6s does (Wilson, 2018).

Despite the significant environmental impact of smartphones, most previous studies have investigated other areas, such as the food industry (e.g., Egilmez, Kucukvar, Tatari, & Bhutta, 2014), the automobile industry (e.g., Nakamichi, Hanaoka, & Kawahara, 2016), air-conditioner

producers (e.g., Huang, Wang, Zhang, & Pang, 2016), electronics in general (e.g., Belkhir & Elmeligi, 2018; Hsu, Kuo, Chen, & Hu, 2013), and the chemical industry (Zhang, Shah, Wassick, Helling, & Van Egerschot, 2014). Few studies have investigated the environmental impact of producing mobile phones (e.g., Migdadi, 2015, 2016; Suckling & Lee, 2015; Belkhir & Elmeligi, 2018). The later study by Migdadi (2016) reported the best practices of the green operations strategy, but the focus of this study was found to be too broad in terms of green indicators. The best practices were found to be related to waste management and recycling. This study did not examine in depth the impact of green actions in GHG emissions, and it did not discriminate between the scope of different GHG emissions (1, 2, and 3). The earlier study by Migdadi (2015) reported the design of effective green base stations, so green actions of the mobile phone producers were beyond its scope. Another study by Belkhir and Elmeligi (2018) evaluates and forecasts the carbon footprint of the electronic sector in general with some focus in mobile phone producers in particular and projects the impact by 2040. The study by Suckling and Lee (2015) evaluates the environmental impact of smartphones. The last two studies do not investigate what actions are effective in reducing GHG emissions.

No clear investigation of the impact of actions related to each scope of GHG emissions has been included in one study.

Most previous studies have focused in reporting on particular processes, and a limited number of actions in supply chain management. No clear investigation of the impact of actions related to each scope of GHG emissions has been included in one study. Most studies have investigated limited or one scope's action, such as GHG 1 or GHG 3 actions. Accordingly, this study will bridge these research gaps by investigating the whole process of the green supply chain in the mobile phone industry and will discuss all the effective actions adopted, without any preidentified limits. It will also describe the impact of the actions with regard to each scope of GHG, and distinguish one scope from another. To this end, the following objectives were attained:

1. Reporting the change in each scope of GHG emissions (1, 2, or 3) of the mobile phone producers industry over the previous year (2017).

2. Identifying the green supply chain management actions taken in each case to reduce each scope of GHG emissions (1, 2, and 3) over the previous year (2017).

3. Developing indicative models for the relationship between the significant actions taken and the degree of reduction in each scope of GHG emissions (scopes 1, 2, and 3).

4. Developing the value-stream map for effective green supply chain management in reducing the GHG emissions of mobile phone production.

This paper is structured in five sections: The first is the literature review, which gives rise to the conceptual model of the study. The second section describes the research methodology and data analysis techniques used in the study. The third contains the data analysis and findings. The fourth section discusses these. The last section presents the conclusions of the paper, its applications and limitations, and some suggestions for future research.

2 | LITERATURE REVIEW

The performance indicators in practicing green operations can be classified into financial, operational, and environmental. The financial indicators show the cost saved as a result of saving energy and material. The operational indicators show a better use of capacity, improved productivity, and a smaller inventory. The environmental indicators show the reduction of GHG emissions, solid waste, and energy consumed (Guang Shi, Lenny Koh, Baldwin, & Cucchiella, 2012; Zhang & Yang, 2016). Therefore, GHG emissions are one of the environmental performance indicators.

Six gases can be classified as GHG emissions—carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). Data for all of them may be reported separately in metric tons or as equivalent tons of CO_2. Most corporations report GHG emissions as CO_2 metric tons or as CO_2 equivalent. GHG emissions can be classified as direct or indirect; the first kind, which is classified as direct emissions, is called GHG 1 (scope 1), meaning direct GHG emissions from sources that are owned or controlled by the company; for example, emissions from combustion in a company's owned or controlled boilers, furnaces, vehicles, etc. Indirect GHG emissions can be classified into GHG 2 (scope 2) and GHG 3 (scope 3). GHG 2 is the name given to indirect GHG emissions from the direct billing of electricity in a company's owned or leased facilities under the control of the corporation. GHG 3 emissions are the remaining indirect emissions—not the GHG 2 emissions from a company's activities, but emissions produced by sources not owned or controlled by the company. Some examples of scope 3 activities are the extraction and production of purchased materials, transportation of purchased fuels, and use of sold products and services (World Business Council for Sustainable Development and World Resources Institute, 2017).

Not many studies have reported all types of GHG emissions in detail. Most studies have reported GHG 1 (Bazan, Jaber, & Zanoni, 2015; Jaber, Glock, & El Saadany, 2013) or GHG 3 (Blanco, Caro, & Corbett, 2016; Elhedhli, & Merrick, 2012; Haddadsisakht & Ryan, 2018) or both, without differentiating between GHG indicators (e.g., Coskun, Ozgur, Polat, & Gungor, 2016; Egilmez et al., 2014; Huang et al., 2016; Nakamichi et al., 2016; Zhang et al., 2014). As for GHG 2 emissions, most previous studies have not given clear accounts of them.

According to the life-cycle assessment process, all organizations should investigate the environmental impact of their operations over all aspects of their operational processes, products, and materials (Bjørn & Hauschild, 2013; Boehme, Panero, Muñoz, Powers, & Valle, 2009; de Bakker, 2001; Joshi, 1999; Matthews & Small, 2000; Migdadi & Elzzqaibeh, 2018; Migdadi & Omari, 2019), so that CO_2 emissions should be reported for suppliers' practices, logistics processes, business travel, manufacturing, customers' practices, and the operation of offices and facilities.

Previous studies of GHG emissions related to green supply chain practices have focused on examining a few green actions. The surveyed actions in supplier relationship management were the number of different components supplied (Huang et al., 2016) and the number of suppliers (Blanco et al., 2016). The actions in the order fulfillment process (manufacturing) that were surveyed were the location of manufacturers (Nakamichi et al., 2016), the modules of the product line (Huang et al., 2016), manufacturer production rates (Bazan et al., 2015), the capacity of production processes (Azadeh, Raoofi, & Zarrin, 2015; Zhang et al., 2014), processing time (Zhang et al., 2014), and the number of facilities opened (Haddadsisakht & Ryan, 2018).

Logistics management actions were related to the locations of suppliers (Nakamichi et al., 2016), the length of the transportation routes (Azadeh et al., 2015; Elhedhli & Merrick, 2012; Nakamichi et al., 2016) or the distances between suppliers, manufacturers, and customers (Huang et al., 2016; Zhang et al., 2014), the mode of transportation and number of vehicles (Haddadsisakht & Ryan, 2018; Huang et al., 2016; Nakamichi et al., 2016), the number of shipments in a manufacturer's cycle (Bazan et al., 2015), and the capacity of distribution centers (Elhedhli & Merrick, 2012; Jaber et al., 2013). Actions in managing the customer relationship were the size of customer demand (Azadeh et al., 2015; Huang et al., 2016) or the size of customer orders (Zhang et al., 2014).

The studies of logistics, transportation, and distribution management revealed that in the automobile industry, maritime transportation generates a huge amount of emissions, resulting from the space occupied by cargoes of cars (Nakamichi et al., 2016). A more environmentally friendly transportation mode is employed for the low-value components of air-conditioner products (Huang et al., 2016). The cost of setup and holding and, consequently, of emissions, can be reduced if trucks with larger capacities are used and not transferred empty (Bazan et al., 2015). One study finds that the rate of carbon tax decreases by increasing the use of transportation (more capacity and lower carbon emissions per item) (Haddadsisakht & Ryan, 2018). The addition of a carbon tax reduces travel (fewer vehicle kilometers) and thereby reduces transportation cost and opens more distribution centers to satisfy customer demand (Elhedhli & Merrick, 2012).

H1: The more capacity use of the logistics transportation mode, the lower the GHG 3 emissions of the supply chain.

H2: The shorter the transportation distance, the lower the GHG 3 emissions of the supply chain.

Studies of production processes reveal that the indirect CO_2 emissions of the production processes depend on the local electrical resources (Nakamichi et al., 2016). The average onsite carbon footprint of the food industry is about 9.2%, and the average supply chain carbon footprint is about 90.8% (Egilmez et al., 2014). Obtaining equipment requiring lower idle energy during standby and sleeping mode until the next production cycle commences will speed up the production process, as manufacturers would no longer need to shut down the equipment to avoid expending excessive energy on idling. Such equipment is particularly necessary if the facility produces more than one product, as it reduces the setup time for each production batch (Bazan et al., 2015).

H3: Equipment with more energy-saving devices will reduce the GHG 1 emissions of the supply chain.

Studies of supplier relationship management reveal that the greater the pressure to reduce CO_2 emissions in the manufacture of air conditioners, the stronger the incentive to choose closer suppliers without consideration of the best deals financially, which often increases the price of products (Huang et al., 2016). Firms with many suppliers capture a significant portion of the GHG 3 emissions in their supply chains (Blanco et al., 2016). The significant actions were related to inventory level, which affects the production cost and the GHG emissions (Jaber et al., 2013). The training of suppliers and the availability of management systems of carbon information for suppliers were the two significant determinants in selecting suppliers (Hsu et al., 2013).

H4: Choosing closer suppliers will reduce the GHG 3 emissions of the supply chain.

H5: The lower the number of suppliers, the lower the GHG 3 emissions of the supply chain.

H6: Training suppliers to reduce carbon emissions will reduce the GHG 3 emissions of the supply chain.

H7: The availability of a management system of carbon information for suppliers will reduce the GHG 3 emissions of the supply chain.

Studies of customer relationship management reveal that the industries considered closer to their customers account more often for lower GHG 3 emissions than do upstream suppliers, who are closer to these industries (Blanco et al., 2016). According to Coskun et al. (2016), customers are classed in different segments according to their "green" expectations: greener, inconsistent, and red. The retailer will redesign the supply chain according to customers' green requirements. If more greening is required, the retailer will ask the supplier to tailor his requirements to satisfy the greening requirements. Customers in different segments may react differently to price increases as a result of greening requirements: inconsistent customers are less willing to pay for more greening; hence, suppliers and retailers serving these customers should pay more attention to reducing the cost of their inputs.

H8: The more "green" the customers' requirements, the lower the GHG 3 emissions of the supply chain.
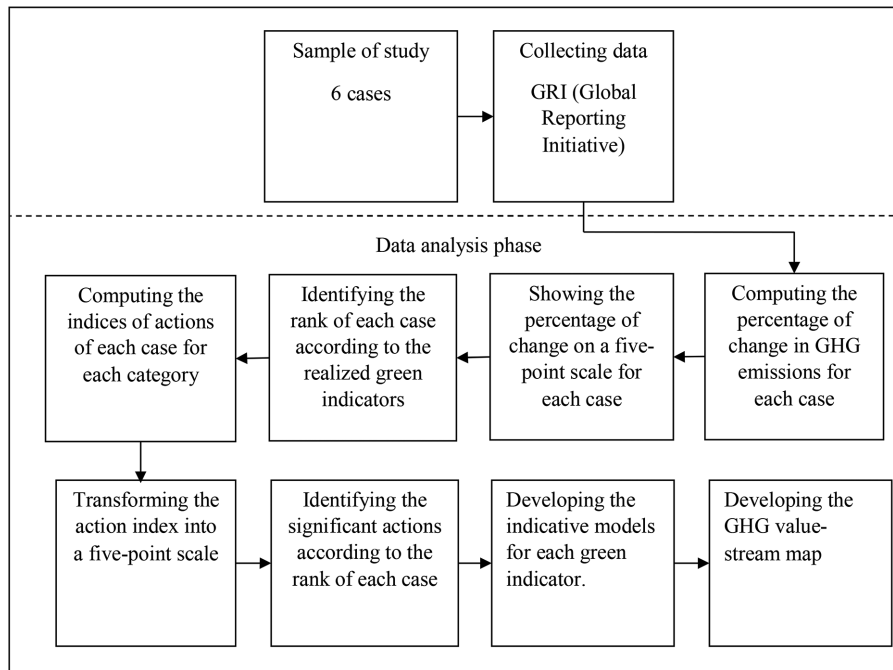
EXHIBIT 1   Flowchart of the research methodology

EXHIBIT 2   Study sample's market share

Corporations	Market share (StatCounter, 2018)
Samsung	30.8%
Apple	20.66%
Huawei	7.57%
LG	3.11%
Nokia	1.24%
ZTE	0.57%
Total market share	63.95%

EXHIBIT 3   Definitions of the GHG indicators as reported by the corporations

GHG indicator	Definition
GHG 1	Million metric tons of direct carbon dioxide equivalent for the energy used in the facilities owned and controlled by the corporations.
GHG 2	Million metric tons of indirect carbon dioxide equivalent for the electricity purchased from a utility provider for the facilities owned or controlled by the corporations.
GHG 3	Million metric tons of indirect carbon dioxide equivalent of upstream and downstream activities out of the corporation ownership or direct control, such as logistics, suppliers' activity, and customer use.

3 | RESEARCH METHODOLOGY AND METHODS

The figure in **Exhibit 1** shows the process flowchart of the present research methodology. It can be seen that this methodology passed through different phases: the first phase was to identify the study sample, followed by collecting the required data, and the last phase was data analysis. The data analysis phase involved eight steps, from computing the percentage of change in the green indicators for each case to developing the value-stream map. The following sections explain in more detail the phases and steps of the research methodology.

3.1 | The study sample

The sample used in the present study was a convenience sample determined by the availability of secondary published data. The sample concerned the green actions reported by corporations and the green indicators in their sustainability reports; however, the sample used in this study is also representative of the industry, as it covers more than 60% of the market share (see the table in **Exhibit 2**).

3.2 | Data collection

The data were all derived from published sustainability reports. The reports were retrieved from the Global Reporting Initiative (GRI) database. The GRI is an independent international organization established in the United States in 1997. It seeks to help organizations to report their impact on sustainability. It develops standards for reporting sustainability and publishes reports via its website (GRI, 2018). The data collected were related to green indicators (namely, GHG 1, GHG 2, and GHG 3) over the recent year (2017) and the actions taken for each case. The table in **Exhibit 3** shows the definition of GHG indicators. To find out more about the actions of green supply chain management of this study, see Section 4.2.

3.3 | Data analysis phase

The form of data analysis that we adopted is called rank analysis, as the cases were ranked according to the degree shown on the green indicators. The following detailed procedure was followed for this purpose:
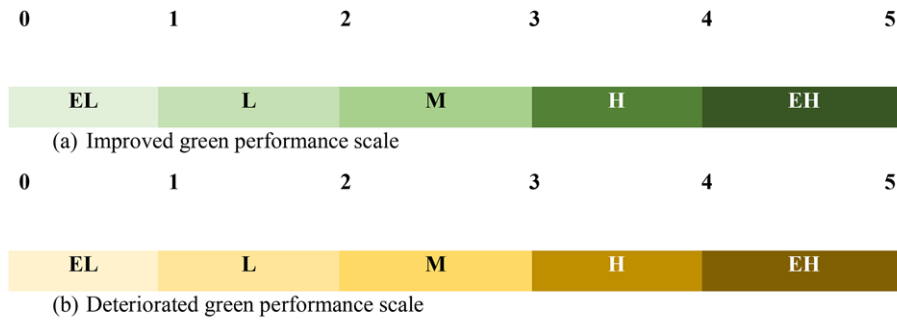
Notes: **EL** = Extremely Low   **L** = Low   **M** = Moderate   **H** = High   **EH** = Extremely High

EXHIBIT 4   Rating scale of green performance [Color figure can be viewed at wileyonlinelibrary.com]

Step 1: Computing the percentage of change in the green indicators for each case. In this study, three indicators were reported: GHG 1, GHG 2, and GHG 3. The following formula was used for this purpose:

% of change in green indicator

$$= \left[(P_{2017} - P_{2016}) / P_{2016} \right] \times 100\%$$

Step 2: Showing the percentage of change on a five-point scale for each case, as presented in the figure in **Exhibit 4**. Two scales were adopted: one (called the improved green performance scale) if the performance had improved, and the other one (called the deteriorated green performance scale) if the performance had deteriorated. In the case of GHG 1, GHG 2, or GHG 3, an improved performance means a reduction in emissions, for example −26%. Conversely, a poorer performance means an increase in emissions, for example +12%.

The rating score was developed by using the benchmarking technique. In this technique, the best improved performance score was identified and used to create a benchmark for the purpose of comparison. Then, the percentage registered in each case was divided by the best score when the performance was improved, or divided by the worst score when the performance had deteriorated, and then multiplied by 5. The following formula summarizes this. The table in **Exhibit 5** shows an illustrative example.

(performance of case (A))/(best performance score)

× 5 improved performance

(performance of case (A))/(worst performance score)

× 5 deteriorated performance

Step 3: Identifying the ranking of each case according to the green indicators registered (GHG 1, GHG 2, GHG 3). The rank was identified according to the level of the rating scale, which was realized by each case. The ranking appears in the table in Exhibit 5 in the previous example. It can be seen that

EXHIBIT 5   Example of the percentage of green performance shown on a five-point scale

GHG1				
Case	**%**	**Scaled on 5 points**	**Level**	**Rank**
Nokia	-24%	-24%/-24%= 1 x 5 = 5	EH	1
Apple	-7%	-7%/ -24%= 0.29 x 5 =1.46	L	2
Huawei	-5%	-5%/-24%= 0.21 x 5 =1.04	L	2
ZTE	-4.7%	-4.7%/-24%= 0.20 x 5 =0.94	EL	3
Samsung	20%	20%/24%= 0.83 x 5 =4.17	H	4
LG	24%	24%/24%=1 x 5= 5	EH	5

Note: The best green performance score was −24%, and the most deteriorated green performance was score +24%.

Nokia is ranked first, followed by Apple and Huawei, the third rank is occupied by ZTE, the fourth by Samsung, and the last is LG.

Step 4: Computing the indices of the actions of each case for each category, following Migdadi (2018). This was done by dividing the number of actions taken by the case by the total number of actions. The example in the table in **Exhibit 6** shows the procedure.

Step 5: Showing the action index on a five-point scale. This was done by multiplying the index by 5.

Step 6: Attaching the indices of the actions to cases according to their ranks and identifying the significant actions. A significant action is one taken by a case (as shown by the rating scale) that is higher in rank than all the lower-ranked cases. (For more detail about the action indices, action rating, ranking, and significant actions, see Appendices 1 to 3).

Step 7: Developing the indicative models for each green indicator. For this purpose, the following procedures were adopted:

Step 7-1: Identifying all of the significant actions affecting the green indicator for each case.

Step 7-2: Summing the significant action indices all together.

EXHIBIT 6 Example of computing the green indices of the actions

Green actions	Apple	Huawei	ZTE	Samsung	LG	Nokia
Reducing the use of energy by facilities						
Investing in gas treatment facilities					1	
Upgrading to LED lighting	1					1
Using natural ventilation and natural lighting		1				
Installing new energy-saving equipment and designs		1				
Using renewable sources of energy			1	1		
Total # of actions taken by each case	1	2	1	1	1	1
Index = Total # of actions taken/total number of actions	1/5 = 0.2	2/5 = 0.4	1/5 = 0.2	1/5 = 0.2	1/5 = 0.2	1/5 = 0.2

EXHIBIT 7 Example of how to show the action indices on a five-point scale

Green actions	Apple	Huawei	ZTE	Samsung	LG	Nokia
Index of reducing the use of energy by facilities	0.2	0.4	0.2	0.2	0.2	0.2
The rating = index × 5	0.2 × 5 = 1.0	0.4 × 5 = 2.0	0.2 × 5 = 1.0	0.2 × 5 = 1.0	0.2 × 5 = 1.0	0.2 × 5 = 1.0

EXHIBIT 8 Example of developing an indicative model

| ZTE	Energy = −24%			GHG 1 = −26.5%	
Step 7-1	**Index**	**Step 7-3 Relative**	**Step 7-5 Impact**	**Step 7-5 direct Impact on GHG 1**	**Step 7-6 mediating**
Process redesign	0.33	0.33/1.33 = 0.25	−24% × 0.25 = −5.98%	−26.5% × 0.25 = −6.64%	5.98% × 6.64% = −0.40%
Technological improvement	0.67	0.67/1.33 = 0.50	−11.95%	−13.28%	−1.59%
Product design	0.33	0.33/1.33 = 0.25	−5.98%	−6.64%	−0.40%
Step 7-2	1.33		−24%	−26.5%	−6.35%

Step 7-3: Dividing the index of each action by all of the indices of action computed in the previous step. The result is the relative impact of each action.

Step 7-4: Computing the average improvement in green performance by deducting the average improvement percentage in the green performance of the lower-ranked cases from that in the case showing greater improvement (for more details about this, see Appendix 4).

Step 7-5: Multiplying the relative impact of the action by the improved performance of the case. The result indicates the impact of the action on improving the green indicator.

Step 7-6: If the case has registered a significant improvement in energy in comparison with all of the lower-ranked cases, the indicative models will have a mediating impact on energy; accordingly, the indicative model will be developed first for its direct impact on reducing energy, and then for its direct impact on reducing GHG. Next, the direct impact on energy will be multiplied by the

EXHIBIT 9 Icons of the value-stream map of the green supply chain

Icon	Interpretation
	Green business travel and transportation
	Green product design
	Green facilities management
	Green manufacturer process Green supplier process
	Green customer practices
	Green logistics process
	Movement

direct impact on reducing GHG emissions. The following example in the table in **Exhibit 8** shows this.

Step 8: Developing a value-stream map of the green supply chain. The value-stream map is a flowchart of value, which has been

(a) Total value for each process

(b) Total value across process
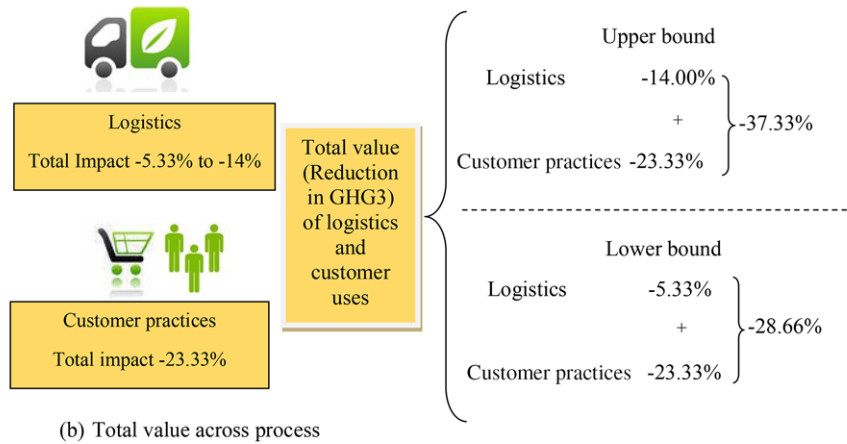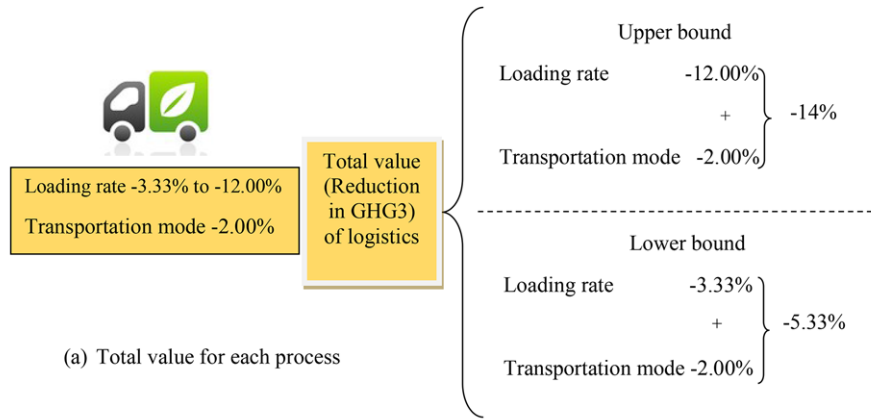
EXHIBIT 10 How to compute total value (total reduction in GHG emissions) [Color figure can be viewed at wileyonlinelibrary.com]

EXHIBIT 11 Degree of change in GHG emissions

GHG 1				GHG 2				GHG 3			
Case	%	scale 5 points	Level	Case	%	Scale 5 points	Level	Case	%	scale 5 points	Level
Nokia	-24%	5	EH	Apple	-7%	1.46	L	Samsung	-14%	2.92	M
Apple	-7%	1.46	L	Nokia	-7%	1.46	L	Nokia	-6%	1.25	L
Huawei	-5%	1.02	L	ZTE	-4.7%	0.94	EL	ZTE	-4%	0.83	EL
ZTE	-4.7%	0.94	EL	Huawei	-2%	0.33	EL	LG	-2%	0.42	EL
Samsung	20%	4.17	H	LG	9%	1.88	L	Huawei	18%	3.75	H
LG	24%	5	EH	Samsung	24%	5	EH				

EXHIBIT 12 Green supply chain management actions taken to reduce GHG 1 emissions

Production process				
Process redesign	Frequency (N = 6)		*Energy use*	Frequency (N = 6)
Reengineering of the process so as to use hydroelectricity rather than fossil fuels	1		Producing the firm's own renewable energy	1
Engaging in lean production	1		Signing long-term, renewable, energy purchase contracts; Supporting new, local projects that meet the firm's robust renewable energy sourcing principles	1
Technological improvement	Frequency (N = 6)		Launching energy conservation programs	1
			Configuring the building automation system for automatic maximum savings based on conditions outside	1
Fully implementing e-Kanban (electronic JIT pull system for moving material from suppliers toward producers according to customers' orders)	1		Operational and technological measures of energy consumed	1
Making managerial and technological improvements, setting up an electronic information management board	1		Energy conservation through introducing third-party experts to assess energy efficiency	1
Product redesign				
	Frequency (N = 6)			Frequency (N = 6)
Optimizing mobile phone packaging	3		Employing the International Organization for Standardization (ISO), ISO 14040/14044 standards as the basis for life-cycle assessments performed on the firm's products	1
Considering alternatives for substances designated "to be avoided"	1			
Business travel and transportation				
Change work venue	Frequency (N = 6)		*Using of group transportation*	Frequency (N = 6)
Employees working from their homes	1		Growing the firm's coach/bus program	1
Encouraging the use of virtual meetings	2			
Use of sustainable travel facilities	Frequency (N = 6)		Setting up a dedicated transit center	1
Adding new electric vehicle charging ports	1		Organizing shuttle buses between hotels, offices, and airports	1
Choosing shuttle buses that run on renewable energy	1		*Travel route management*	Frequency (N = 6)
Encouraging the use of electric or low-emission cars	2		Eliminating the need for employees to travel	1
Providing new campus bicycles	1		Engaging in internal lobbying and guidance to reduce the need for internal business travel	2

created to show the impact of moving products and services along the supply chain. "Value" in the present research is the percentage of reduction in GHG emissions across the supply chain, whether via upstream, core, or downstream processes. The processes were presented by using the icons as presented in the table in **Exhibit 9**. Under each process, the categories of action were presented, and the percentage of reduction in GHG emissions was related to each action. Each kind of GHG emission was presented in a different color, and the accumulated percentages of each kind of GHG were computed to find an overall GHG. The purpose of developing this map was to make it easier to read the results. The total value (total reduction in GHG emission) was computed for each process and across processes as presented in **Exhibit 10**.

4 | DATA ANALYSIS AND FINDINGS

4.1 | The degree of change in GHG emissions

The table in **Exhibit 11** shows the degree of change in the GHG emissions. It can be seen that the positive change in GHG 1 emissions is wider than in the other indicators: the change varied between −4.7% and −24% for GHG 1 emissions. However, the range of positive change of GHG 3 emissions is wider than the change in GHG 2 emissions, which was between −2% and −14% for GHG 3 emissions, and between −2% and −7% for GHG 2 emissions. In addition, the negative performance of GHG 2 emissions is wider than that of GHG 1 and GHG 3 emissions; it is between 9% and 24%. Being the top-ranked case in terms of any indicator does not mean being the top ranked in other indicators. For example, Nokia was the top ranked in terms of GHG 1 emissions, but

EXHIBIT 13 Green supply chain management actions taken to reduce GHG 2 emissions

Accreditation of facilities	Frequency (N = 6)	Upgrading facilities	Frequency (N = 6)
Meeting a LEED Gold certification	1	Upgrading heating, ventilation, and air-conditioning systems	1
Meeting ISO 50001 international standard certification	2	Replacing old facilities	1
Reducing energy use by the facilities	Frequency (N = 6)	*Controlling energy use by the facilities*	Frequency (N = 6)
Investing in gas treatment facilities	1	Retro-commissioning building and lighting controls	1
Upgrading to LED lighting	2	Installing water heating meters	1
Installing natural ventilation and natural lighting	1	Installing sensors to collect data about electricity, temperature, humidity, flow, and pressure	2
Installing new energy-saving equipment and designs	1	Tracking important energy efficiency indicators	1
Using renewable sources of energy	2	Integrating the software for iEnergy network energy management based in cloud technology	1
		Setting up a comprehensive software platform that will increase the automatic collection and reporting of environmental data	1
		Installing electrical submeters to monitor the use of electric power	1

ranked second in terms of GHG 3 emissions. Moreover, the level of relative performance of a case is not always the same for all indicators. For example, Nokia's performance was extremely high in terms of GHG 1 emissions, but low in terms of GHG 2 and 3 emissions. In addition, the cases that registered negative performance can also register positive performance. Samsung, for example, registered negative performance in terms of GHG 1 and 2, but positive performance in terms of GHG 3.

4.2 | The adopted green supply chain management actions

The table in **Exhibit 12** shows the green supply chain management actions taken to reduce GHG 1 emissions. It can be seen that the actions were divided into three major categories: production process actions, product redesign and business travel actions. The categories of the production process were process redesign, technological improvement, and energy use. The categories related to business travel were changing the work venue, using sustainable travel facilities, using group transportation, and travel route management. In each category, the frequency of actions taken by the mobile phone producers was counted; most of the actions were taken by only one case. However, three actions were taken related to product redesign, the most frequently action was optimizing mobile phone package.

The table in **Exhibit 13** shows the actions taken by the management of the green supply chain to reduce GHG 2 emissions. It can be seen that the categories of action taken were accreditation of facilities, reducing the use of energy in the facilities, upgrading the facilities, and controlling the energy use in the facilities. Different actions were taken in each category. Most of the actions were taken by only one case.

The table in **Exhibit 14** shows the green supply chain management actions taken to reduce GHG 3 emissions. It can be seen that the actions can be divided into three general categories: management of the suppliers' relationship, management of the logistics, and customer practices. The actions taken in managing the relations with suppliers were classified either as auditing suppliers or as helping suppliers. The

logistics management actions were classified according to the loading rate of the transportation facilities or the mode of transportation. The customer practices categories were either to provide customers with more efficient products or to educate customers. Different actions were taken in each category. The frequency with which the actions were taken varied across the categories.

4.3 | The effective green supply chain management actions in reducing GHG emissions

The table in **Exhibit 15** shows the indicative models for the impact of green supply chain management actions in reducing GHG 1 emissions. It can be seen that all of the categories of actions in the production process have an effective impact on reducing GHG 1 emissions. Two categories have both a direct and an indirect impact on reducing GHG 1 emissions. The impact of different categories of production actions is different: the most effective action was controlling energy use, followed by technological improvement, and the action with the lowest direct impact was process redesign. The maximum reductions were -13.14%, -11.95%, and -5.98%, respectively. These results supported H3. However, the indirect impact was through energy saving, the most effective was technological improvement, at -1.59%, followed by process redesign at -0.4%.

The product redesign had a direct and indirect impact on reducing GHG 1 emissions. The impact was between -5.98% and -17.47%. However, the indirect impact was -0.4%. The maximum direct impact of product redesign was more than the categories of action regarding the production process. Two out of four categories of actions regarding business travel had a significant impact on reducing GHG 1 emissions. These categories were using group business travel facilities and using sustainable travel facilities. The impact of these categories was only direct; the impact was -6.18% for using group business travel facilities, and within a range of -4.93% to -9.27% for using sustainable travel facilities.

EXHIBIT 14   Green supply chain management actions taken to reduce GHG 3 emissions

Suppliers relationship management			
Auditing suppliers	Frequency (N = 6)	*Helping suppliers*	Frequency (N = 6)
Conduct audits and inspection for suppliers to find opportunities for energy efficiency	4	Developed the Clean Energy Portal, an online platform to help suppliers identify commercially viable renewable energy solutions	1
Impose a comprehensive qualification process for all new suppliers, including suppliers' sustainability systems	2	Update policy guidance and tools to help suppliers develop commercially viable strategies to achieve renewable energy	1
		Train suppliers to identify opportunities for energy efficiency	4
		Help suppliers to analyze root causes and identify ways to mitigate issues	3
		Encourage suppliers to develop energy metering systems, audit their energy use, and identify opportunities to cut energy use and CO_2 emissions	2
Logistics management			
Loading rate of transportation facilities	Frequency (N = 6)	*Transportation mode*	Frequency (N = 6)
Using less packaging so less fuel is consumed when products travel by air and sea	3	Using containers and ships	2
Making packaging lighter so less fuel is consumed when products travel by air and sea	3		
Customer practices			
Providing customers with more efficient products	Frequency (N = 6)	*Educating customers*	Frequency (N = 6)
Make advancements in products' efficiency so mobile phones can charged only once a day	1	Completion of an environmental product declaration, or EPD, containing, product-related information based on regulatory requirements for customers	1
Using high-efficiency chargers	1		
Incorporating an ultra-power-saving mode	2		

EXHIBIT 15   Effective actions in reducing GHG 1 emissions

Category of actions	Direct reduction in GHG 1 emission (%)		Indirect reductions in GHG 1 emission through reducing energy consumption (%)
Production process			
Process redesign	−5.98%	⸺	−0.40%
Technological improvement	⸺	−11.95%	−1.59%
Energy use	⸺	−13.14%	⸺
Product redesign			
Product design	−5.98%	−17.47%	−0.40%
Business travel and transportation			
Use of group transportation	−6.18%	⸺	⸺
Use of sustainable travel facilities	−4.93%	−9.27%	

EXHIBIT 16   Effective actions in reducing GHG 2 emissions

Actions	Reduction in GHG 2 emissions (%)	
Controlling the use of energy in facilities	−4.36%	−13.73%
Accreditation of facilities	−7.63%	−14.79%
Reducing the use of energy in facilities	−6.11%	⸺

The table in **Exhibit 16** shows the indicative models of the impact of actions taken by the management of green supply chains to reduce GHG 2 emissions. It can be seen that only three actions have a direct impact on reducing GHG 2 emissions, and two of these actions have a range of impacts. These actions involved controlling the use of energy in the facilities and the accreditation of facilities. The impact was between −4.36% and −13.73% for controlling the energy use in the facilities; however, the impact of accrediting the facilities ranged between −7.63% and −14.79%. The impact of reducing the energy use of facilities was −6.11%. The most effective action was the accreditation of facilities.

The table in **Exhibit 17** shows the indicative models to reduce GHG 3 emissions. It can be seen that two categories had a significant impact,

EXHIBIT 17 Effective actions in reducing GHG 3 emissions

Actions	Reduction in GHG 3 emission (%)	
Logistics management		
Loading rate of transportation facilities	−3.33%	−12.00%
Transportation mode	−2%	—
Customer practices		
Educating customers	−3.33%	—
Providing customers with more efficient products	—	−20%

namely, logistics management and customer practices. The loading rate of the transportation facilities had more impact than the mode of transportation; it ranged from −3.33% to −12% for the loading rate of the transportation facilities, while the impact of the transportation mode was −2%. This result supported H1, but not H2. Providing customers with more efficient products had the greatest impact on reducing GHG 3 emissions, with a −20% reduction. The impact of educating customers was −3.33%; this result supports H8. The management of the relationship with suppliers had no significant impact on reducing GHG 3 emissions. Accordingly, hypotheses H4, H5, H6, and H7 are rejected.

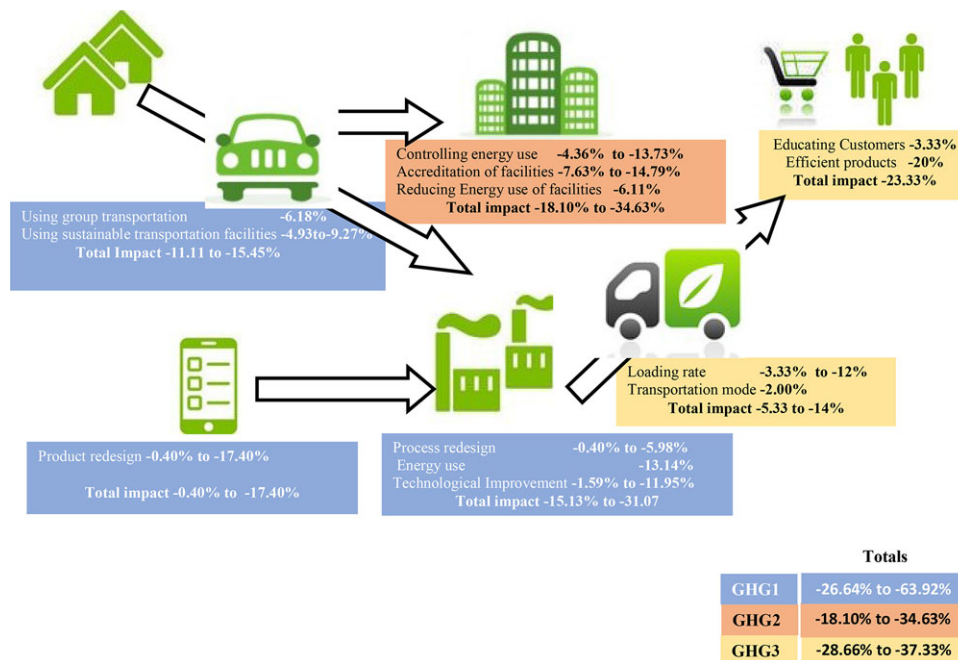## 4.4 | The value-stream map of the green supply chain GHG for mobile phone producers

The figure in **Exhibit 18** shows the value-stream map for the effective supply chain management of mobile phone producers (to have better insight about how the values were computed, see Exhibit 10). It can be seen that three processes contribute to reducing GHG 1 emissions, namely, business travel, product redesign, and the production process, (the color of labels under these processes is blue). It can be seen that

the most effective process in reducing GHG 1 emissions was making changes in the production process. The total impact was between −15.13% and −31.07%. The total impact of changes in product design ranged between −0.4% and −17.40%, and the total impact of altering business travel was between −11.11% and −15.45%. The total impact of green facilities management was between −18.10% and −34.63%, (the color of label under this processes is orange). Two processes had a significant impact on reducing GHG 3 emissions were logistics management and customer practices, (the color of labels under these processes is yellow). The total impact of the customer practices process was −23.33%, and it exceeded the impact of the logistics process, which was between −5.33% and −14.00%. The total impact of reducing GHG 1 emissions was mostly within the range of −26.46% to −63.92%, followed by reducing GHG 3 emissions, which ranged between −28.66% and −37.33%, and the lowest total impact was for GHG 2 with a range of between −18.10% and −34.63%.

5 | DISCUSSION

The greater improvement in the reduction of GHG 1 emissions compared with the reductions of the other indicators is due to the fact that the production process, as the greatest contributor to GHG 1 emissions, causes the greatest amount of concern to the producers of mobile phones. The statistics show that 85% of emissions come from the production process (Suckling & Lee, 2015). The range of improvement in GHG 3 emissions was greater than those realized from GHG 2 reductions, as GHG 3 emissions are related to many processes, such as logistics, customer use, etc. Thus, the accumulated improvement can exceed the improvements in GHG 2 emissions.

The impact of energy use in the production process on reducing GHG 1 was greater that than for process redesign and

EXHIBIT 18 Value-stream map of the green supply chain GHG by mobile phone producers [Color figure can be viewed at wileyonlinelibrary.com]

technological improvement, as the action of reducing energy usage has a more direct impact on GHG 1 emissions than on other changes, especially if corporations are committed to using sustainable energy or reducing energy use as was the case in the effective corporations in the present research. The use of sustainable traveling facilities has more impact than using group transportation facilities, as sustainable traveling facilities have a more direct impact on the amount of fuel used than group transportation does. Many factors can impact the use of group transportation, such as the willingness of employees to use it, the availability of group transportation, etc., but the replacing of facilities by sustainable equivalents, whether it is a group or a single facility, has a direct impact, leaving aside the employees' willingness to use it or its availability.

Product redesign had the most significant impact on reducing GHG 1 emissions, as the redesign of a product—whether by using different materials or substances that require less energy in the production process—will have an impact on the production process. Using less packaging will also reduce packing time. Furthermore, the assessment of environmental impact during a product's lifecycle will have an impact on the design requirements; it will call for more recycling, remanufacturing, and upcycling of products, which will reduce the GHG 1 emissions of the production process. The study of Migdadi (2016) confirms that some of the best practices of mobile phones producers' operations strategy were related to recycling.

The accreditation of facilities has provided greater improvement in the reduction of GHG 2 emissions than controlling the energy use of facilities and reducing the use of facilities. This indicates that the accreditation of energy savings by using Leaderships in Energy and Environmental Design (LEED; United States Green Building Council, 2018) or International Organization for Standardization (ISO) 50001 standards was more effective than taking action without accreditation. For example, ISO 50001 (ISO, 2018) is based on the management system model of continual improvement, which is also used in other well-known standards, such as ISO 9001 and ISO 14001. This makes it easier for organizations to integrate energy management into their overall efforts to improve quality and environmental management (ISO, 2018). Adopting the LEED system also includes a set of rating systems for the design, construction, operation, and maintenance of green buildings, homes, and neighborhoods, which aims to help building owners and operators be environmentally responsible and use resources efficiently (US Green Building Council, 2018). The accreditation process requires auditing, either internally or externally, to confirm conformance. Moreover, the accreditation requires periodic evaluation by the accreditation body.

The management of supplier relations had no significant impact on reducing GHG 3 emissions. The results of the actions index in Appendix 2 show that while some actions were taken extremely often, such as auditing suppliers, and some actions taken moderately, may often help suppliers, but these actions did not guarantee an improvement in GHG 3 emissions. Most mobile phones over the last few years have continued to be made in-house by original equipment manufacturers, and few are produced by outsourced manufacturers, such as electronic manufacturing services (EMS; IHS Markit, 2014). Accordingly, the proportion of suppliers' GHG 3 emissions can be very small in comparison with other processes, such as logistics or customer use. The loading rate of transportation facilities caused more reductions in GHG 3 emissions than the mode of transportation. This can be related to the fact that the most widely adopted outboard mode by most producers is aircraft. For example, Apple almost certainly ships by air, despite the higher logistical costs, for two reasons. The first is the cost of working capital. Ocean shipments take 30 days or more to cross the Pacific and reach their final destination in Apple's retail stores, versus a mere 3 to 5 days for air freight (Flexport, 2018). However, for inboard freight the modes are more diverse than for outboard so there are some effects, but the emissions related to outboard shipments may be more significant because of the use of air shipment.

Providing customers with more efficient products had more impact than educating customers. Because the impact of educating customers about environmentally friendly use requires voluntary action by the customer, the corporations have no control over it. Moreover, educating customers in general is a problem of marketing in itself, as many companies do not differentiate between marketing and educating. "Educating" means putting the product in the context of its actual use, so the producer should communicate advice about the product's use in simple, professional, and familiar words (Craig, 2015). This can be challenging in the context of green product use, as the adoption of green practices by customers depends on his/her willingness to protect the environment.

6 | CONCLUSIONS

6.1 | Contribution and results

The environmental impact of the mobile phone manufacturing industry is becoming increasingly significant. GHG emissions from this industry will reach more than 14% of global emissions. The production process is responsible for about 85% of mobile phone production emissions; accordingly, it seems prudent to study the most effective supply chain actions to reduce the environmental impact of this sector. This paper has reported on the literature regarding effective actions taken in other sectors, and surveyed some actions or action categories; however, many of these studies showed limited concern about differentiating among GHG 1, 2, and 3 emissions. Accordingly, this study bridged the gap in the literature by investigating all the action categories for mobile phone producers.

The study found that the total improvement in GHG 1 was more than for GHG 2 or GHG 3. The most effective actions for reducing GHG 1 emissions were saving energy in the production process, addressing product design, and using sustainable transportation facilities. However, the most effective action for reducing GHG 2 emissions was the accreditation of facilities, and the most effective actions for reducing GHG 3 emissions were the loading rate of the transportation facilities and providing customers with more efficient products. The indicative models were developed in this research for measuring the impact of green supply chain actions on GHG emissions, and the research also provided a value-stream map, which shows the impact of all the supply chain actions in reducing GHG emissions.

6.2 | Implications, limitations, and future research

The results of this study will help the supply chain managers of the mobile phone manufacturing industry adopt the effective actions reported by this study. Moreover, academics will improve their insights into the effective actions that can be taken by the managers of green supply chains in mobile phone manufacturing. This study can be used for teaching purposes and for conducting future research. The study is limited in terms of sample size, considering six corporations only, but the models developed by this study are still indicative. However, further studies with larger sample sizes could help in developing prediction models of greater validity. Certain aspects require further in-depth investigation in future studies, such as the impact of saving energy in the production process, the accreditation of facilities, the adoption of sustainable transportation facilities, the management of supplier relations, and customer education.

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APPENDIX 1: INDICES OF GHG 1 SUPPLY CHAIN MANAGEMENT ACTIONS

Corporation	GHG 1			Process redesign			Technological improvement			Energy usage			Product design		
	%	Scale	Level	Index	Scale	Level	Index	Scale	Level	Index	Scale	Level	Index	Scale	Level
Nokia	-0.24	5	EH	0	0	None	0	0	None	0	0	None	1	5	EH
Apple	-0.068	1.46	L	0.33	1.67	L	0.00	0.00	None	0.33	1.67	L	0.33	1.67	L
Huawei	-0.049	1.02	L	0.00	0.00	None	0.33	1.67	L	0.67	3.33	M	0.00	0.00	None
ZTE	-0.045	0.94	EL	0.33	1.67	L	0.67	3.33	M	0	0	None	0.33	1.67	L
Samsung	0.2	-4.17		0	0	None	0	0	None	0	0	None	0	0	None
LG	0.24	-5		0	0	None	0	0	none	0	0	none	0	0	None

Changing working venue			Use of group transportation			Use of sustainable travel facilities		
Index	Scale	Level	Index	Scale	Level	Index	Scale	Level
0.5	2.5	M	0.67	3.33	H	0.25	1.25	L
0.5	2.5	M	0.33	1.67	L	0.5	2.5	M
0	0	None	0	0	None	0.25	1.25	L
0	0	None	0	0	None	0	0	None
0.5	2.5	M	0	0	None	0	0	None
0	0	None	0	0	None	0	0	None

Shaded actions: better rank in comparison with all lower-ranked cases.
None: action is not taken by the case.

APPENDIX 2: INDICES OF GHG 2 SUPPLY CHAIN MANAGEMENT ACTIONS

Corporation	GHG 2			Accreditation of facilities			Reducing energy use of facilities			Upgrading facilities			Controlling energy use of facilities		
	%	Scale	Level	Index	Scale	Level	Index	Scale	Level	Index	Scale	Level	Index	Scale	Level
Apple	-0.07	1.46	L	0	0	None	0.2	1	EL	0.5	2.5	M	0.14	0.71	EL
Nokia	-0.07	1.46	L	0.5	2.5	M	0.2	1	EL	0	0	None	0.57	2.86	M
ZTE	-0.045	0.94	EL	0.5	2.5	M	0.2	1	EL	0	0	None	0.14	0.71	EL
Huwawei	-0.016	0.33	EL	0.5	2.5	M	0.4	2	L	0	0	None	0.29	1.43	L
LG	0.09	-1.875		0	0	None	0.2	1	EL	0	0	None	0	0	None
Samsung	0.24	-5		0	0	None	0.2	1	EL	0.5	2.5	M	0	0	None

Shaded actions: better rank in comparison with all lower-ranked cases.
None: action is not taken by the case.

APPENDIX 3: INDICES OF GHG 3 SUPPLY CHAIN MANAGEMENT ACTIONS

Corporation	GHG 3			Suppliers relationship management						Logistics					
				Auditing suppliers			Helping suppliers			Loading rate of transportation facilities			Transportation mode		
	%	Index	Scale	Index	Scale	Index	Scale	Index	Scale	Index	Scale	Level	Index	Scale	Level
Samsung	-0.14	0.50	2.50	0.5	2.5	M	0.2	1	EL	0	0	None	0.50	2.50	M
Nokia	-0.06	0.00	0.00	0	0	none	0	0	none	1	5	EH	1.00	5.00	EH
ZTE	-0.04	1.00	5.00	1	5	EH	0.2	1	EL	1	5	EH	0.00	0.00	None
LG	-0.02	0.00	0.00	0	0	none	0.4	2	L	0	0	None	0.00	0.00	None
Huawei	0.18	1.00	5.00	1	5	EH	0.6	3	M	0	0	None	0.00	0.00	none

Customer use					
Provide customers with more efficient products			Educate customers		
Index	Scale	Level	Index	Scale	Level
0.00	0.00	None	0.00	0.00	None
0.00	0.00	None	1.00	5.00	EH
0.00	0.00	None	0.00	0.00	None
0.33	1.67	L	0.00	0.00	None
0.00	0.00	None	0.00	0.00	None

Shaded actions: Better rank in comparison with all lower-ranked cases.
None: The action is not taken by the case.

APPENDIX 4: RELATIVE GHG EMISSIONS ACROSS CASES

GHG 1							
N	AL	A	HL	H	ZL	Z	SL
Nokia	Apple	Apple	Huawei	Huawei	ZTE		Samsung
	Huawei		ZTE		Samsung	ZTE	LG
	ZTE		Samsung		LG		
	Samsung		LG				
	LG						
−24%	+6%	−7%	+8%	−5 %	+13%	−4.7%	+22%
N – AL	−30%	A – HL	−15%	H – ZL	−18%	Z – SL	−26.7%
GHG 2							
A	NS	A	ZS	Z	HS	H	LS
Apple	Nokia	Nokia		ZTE		Huawei	
	ZTE		ZTE		Huawei		
	Huawei		Huawei		Huawei		
	LG		LG		LG		LG
	Samsung		Samsung		Samsung		Samsung
−7%	+4%	−7%	+7%	−4.7%	+10.3%	−2%	+16.5%
A – NS	−11%	N – ZS	−14%	Z – HS	−15%	H – LS	−18.5%
GHG 3							
S	NH	N	ZH	Z	LH	L	H
Samsung	Nokia	Nokia		ZTE		LG	
	ZTE		ZTE		LG		
	LG		LG		LG		
	Huawei		Huawei		Huawei		Huawei
−14%	**+1.5**	−6%	+4%	−4%	+8%	−2%	+18%
S – NH	−15.5%	N – ZH	−10%	Z – LH	−12%	L – H	−20%