Int. J. Production Economics 275 (2024) 109327

Contents lists available at ScienceDirect

International Journal of Production Economics

journal homepage: www.elsevier.com/locate/ijpe

A TOE-DCV approach to green supply chain adoption for sustainable operations in the semiconductor industry

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A R T I C L E I N F O

Keywords:
Green supply chain
Semiconductor industry
Sustainability
Dynamic capability
Risk
Resilience

A B S T R A C T

Semiconductor industry plays a critical role for the global economy. Semiconductor industry provides various necessary technologies such as IoT, AI, modern fabrication technologies and so on to various industries including automotive industry, electronic and communication industry, healthcare industry, construction and building industry, space industry, and so on. However, semiconductor supply chain experiences various supply chain related risks and challenges because of its procedural complexities, global supply chain integrations, government policy and regulations, competitiveness, technological complexities, and so on. Not many studies available which investigated the risk, resilience, and complexities regarding green supply chain adoption by semiconductor industry. In this context, the objective of this study is to examine the risks, resilience, and complexities for managing the green supply chain adoption for higher sustainability in the semiconductor industry. Utilizing the TOE framework (Technology-Organization-Environment) and DCV (Dynamic Capability View), we developed a research model to achieve this purpose. Subsequently, this model was validated through structural equation modelling, involving 356 respondents affiliated with the semiconductor industry. This study highlights that technological risk aspects comprising of technological turbulence and risk, compatibility and complexity, organizational dynamic capabilities, and resilience along with appropriate policy and regulations could help successful adoption of green supply chain management in the semiconductor industry.

1. Introduction

Semiconductors are vital components of modern electronics. They are used in many diverse products, such as phones and computers to cars and health devices. The devices mentioned above, and others use microchips, memory units, and chipsets. The semiconductor supply chain is a complex network that involves companies that design, make, test, pack, and distribute semiconductors (Li et al., 2011; Oliveira et al., 2019). It is the interconnected framework of entities responsible for the various stages in the lifecycle of semiconductor products. The supply chain is complicated, requiring the alignment of several different steps, from getting parts and materials to the delivery to the ultimate customer (Browning et al., 1995; Lai et al., 2022). A complicated web of companies, organizations, and people make up the semiconductor supply chain. They work on the creation, production, quality control, packaging, and delivery of semiconductors. The semiconductor supply chain usually has several steps involving complex supply chain flow (Oliveira et al., 2019). It is to note that for ensuring green innovation to establish a healthier society, adoption of green supply chain management (GSCM) is needed for semiconductor industry. Besides, semiconductor chips manufactured in specialized plants also release carbon content gas polluting the atmosphere (Awa and Ojiabo, 2016). To address these

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https://doi.org/10.1016/j.ijpe.2024.109327
Received 29 December 2023; Received in revised form 27 May 2024; Accepted 1 July 2024
Available online 2 July 2024

issues, it is essential to use the GSCM process that could help to mitigate such environmental hazards. Supply Chain Management (SCM), which supports the success of many leading companies, is a key element of operations management (Teece, 2014a; Stekelorum et al., 2021; Vrontis et al., 2022a). The competitive landscape is not shaped by individual organizations, but by supply chains that have multiple workflows across collaborating partners (Hwang et al., 2016). It is worth mentioning that GSCM practices are important for creating ecofriendly products (Tseng et al., 2019). In the supply chain flow followed in the semiconductor industry, it is needed to resist disruptions of flow of supply of semiconductor chips. This needs the supply chain flow to be more resilient to ensure better performance of manufacturing plants of semiconductor chips which necessitates use of GSCM practices (Li et al., 2011). The strategic SCM is a process that involves multiple interactions among various factors such as strategic sourcing orientation for lasting partnerships, communication between firms, teams across organizations and integration of buyers and suppliers (Chen & Paulraj, 2004). As many businesses source, sell, or compete globally or with global competitors (Oliveira et al., 2019), they use strategic management theories to find ways to cooperate and gain an edge in a global setting. Therefore, many firms and business schools have focused their attention on Global SCM (Browning et al., 1995; Chaudhuri et al., 2022; Lai et al., 2022). In the semiconductor industry, the global production scenario prevails, characterized by a supply chain network spanning the globe (Lee et al., 2010). Dominated by leading technology-based firms, this industry demands cost efficiency, mass production, and operational flexibility. The semiconductor industry is characterized by its high demand for capital, as it involves sophisticated R&D processes, with few companies that can compete in the market. Management models in this global industry rely heavily on outsourcing and offshoring in SCM processes (Pan et al., 2015). Stekelorum et al. (2021) contend that implementing green supply chain management (GSCM) would enhance the global semiconductor industry's supply chain network in terms of effectiveness, sustainability, and environmental friendliness. It is important to mention here that the regulatory bodies of all the industries strive to motivate the firms to be environmentally conscious and restrict their activities binding them with some salient regulations to be followed (Ratusny et al., 2022). In the dynamic business environment, semiconductor industry manufacturing firms need to develop their dynamic capabilities to successfully address the volatile situations for survival (Mousavi et al., 2019; Song & Dong, 2024).

The GSCM processes represent logistic systems designed to facilitate the global production and delivery of products while prioritizing environmental considerations. To do this, companies must spend money on improving the design and planning of their logistic systems, while considering the balance between profits and environmental effects (Geng et al., 2017). Some of the semiconductor manufacturing units have already started using GSCM processes (Stekelorum et al., 2021; Chatterjee et al., 2023). The green supply chain embeds environmental practices into supply chain management, aiming to minimize a product's overall environmental footprint across its entire existence (Lai et al., 2022). As a key objective this study entails the development of a theoretical framework to elucidate various relationship existing amongst factors essential for attaining green supply chain network. Energy consumption (Wang & Lee, 2022) is one of the biggest sustainability issues and threats that the semiconductor industry faces. The production process involves high-temperature ovens and cleanrooms, which lead to high energy consumption (Hu & Chuah, 2003; Li et al., 2011; Wang & Lee, 2022).

The semiconductor industry faces other risks and challenges as well. The industry needs to lower its energy use and increase its energy efficiency to avoid both environmental and economic risks. Another challenge is carbon emissions, which cause climate change (Lin et al., 2020). The industry emits carbon dioxide through the manufacturing process, and it has set targets for reducing greenhouse gas emissions and exploring various methods to achieve these targets, such as adopting renewable energy sources and improving manufacturing processes (Lin et al., 2020). The semiconductor industry also faces a major sustainability challenge in managing resources, especially water scarcity and the reliance on rare earth minerals such as silicon (Lin et al., 2020). For the industry's resilience, it is essential to manage resources sustainably, as these resources could be impacted by geopolitical conflicts, regulatory shifts, or environmental damage (Swain et al., 2022). Labor standards and supply chain transparency are also rising social responsibility issues for the semiconductor industry, as it has a complex global SCM that involves many suppliers and subcontractors. This makes it hard to track working conditions and guarantee compliance with labour standards. More supply chain transparency is needed to make sure that the industry behaves in a moral and green way (Adhi Santharm & Ramanathan, 2022). Several studies have highlighted that the supply chain management system in the semiconductor industry is complex since it requires perfect alignment of various stages right from procuring parts and materials to the delivery for the end users (Browning et al., 1995; Lai et al., 2022). Another study has demonstrated that adoption of GSCM could improve the supply chain management system of semiconductor industry (Stekelorum et al., 2021). Studies have also noticed that the semiconductor industry experiences several risks and challenges in sustaining their supply chain management process and needs to minimize energy consumption during the process for avoiding economic and environmental risks (Lin et al., 2020; Wang and Lee, 2022). Thus, several studies nurtured the aspects of GSCM practices in the semiconductor industry though it has been observed that less attention and studies are emphasized to explicitly nurture how the dynamic capabilities of the firms could impact the adoption of GSCM in the semiconductor industry. Hence, there is a research gap. In this vein, this study seeks to address the following research questions (RQs).

RQ1. How do the issues like risk, resilience, and complexity affect the implementation of GSCM practices in the semiconductor industry?

RQ2. Whether dynamic capabilities of the organizations impact the adoption of GSCM in the semiconductor industry?

RQ3. What are the impacts of government policies and regulations to adopt GSCM practices in the semiconductor industry?

The above research questions (RQs) have been addressed by analyzing the responses of 356 respondents affiliated with the semiconductor industry. This study has also developed a research model which has duly been tested by factor-based partial least square (PLS) – structural equation modelling (SEM) technique. To substantiate the empirical findings, the present study has considered the integrated concepts of technology-organization-environment (TOE) framework and dynamic capability view (DCV) since neither of these two concepts alone could thoroughly investigate how the technological risk aspects, dynamic capability along with organizational resilience and environmental aspects including policy and regulations could facilitate green supply chain adoption by the semiconductor industry. It is pertinent to mention here that issues concerning with technological risks as well as matters related to policy and regulations could be examined with the help of TOE framework whereas issues relating to dynamic abilities of the organizations could be analysed with the support of DCV.

The reminder of the paper is organized as follows. Next to the introduction section, section 2 presents a literature review with hypotheses development followed by research methodology in section 3. Thereafter, section 4 presents analysis of data followed by results and discussion in section 5. Next, section 6 presents implications of this study followed by conclusion in section 7. Finally, section 8 presents the limitations and future scope of this study.

2. Literature review

In this section, the literature on the antecedents of successful implementation of GSCM in the semiconductor industry that includes analysis of risk factors along with resilience has duly been discussed. Also, the concern theories and framework which could assist to develop the hypotheses have also been discussed. Moreover, studies have suggested how different factors impact the adoption of new technologies in different organizations as well as how some of these factors could also impact the adoption of sustainable supply chain practices in the semiconductor industry (Kim et al., 2014; Hwang et al., 2016; Khan et al., 2021). Studies have also highlighted how different factors could impact the adoption of new technologies such as RFID in the manufacturing industry (Wang et al., 2010; Lai et al., 2022). Also, there are studies which have demonstrated how different adoption models such as TAM, TOE, and so on could help to identify the antecedents that are necessary to adopt AI in production and manufacturing industry (Chatterjee et al., 2021; Hwang et al., 2016; AL-Khatib et al., 2023). Besides, studies have also demonstrated how dynamic capabilities of the firms could help to articulate proper strategy for successfully adopting new technologies in the firms (Vogel and Güttel, 2013; Mousavi et al., 2019; Song & Dong 2024) and how social media could help to facilitate adoption of new technologies in the firms (Nasrollahi, 2018; Ye et al., 2022; Yu et al., 2024). All these studies help to examine and investigate the pros and cons of adoption of GSCM practices in the semiconductor industry.

2.1. Adoption of GSCM in semiconductor industry

The semiconductor industry is an essential sector that supports technological progress in various industries. Various sustainability issues, such as energy use, carbon output, resource management, and social responsibility matters (Lin et al., 2020), affect this industry. It is increasingly important to examine efficient methods and approaches to address these issues and support sustainable development in the semiconductor industry. Electronic systems and electronic cars rely on electronic chips for their functioning. One of the first major challenges for the electric vehicle industry is this shortage of chips (Van Do et al., 2021). The pandemic increased the demand for products that use semiconductors, putting stress on the factories and designers of chips to meet the needs in a short time during a crisis (Galati et al., 2021; Frieske and Stieler, 2022). The semiconductor industry has faced many difficulties, but it has begun to pay attention to sustainability, with many companies aiming for high goals to lower their environmental footprint and enhance their social responsibility (Sueyoshi and Ryu, 2021; Khorana & Kizgin, 2022). Carbon neutrality and energy efficiency are among the goals that Intel and Samsung have established for themselves. Moreover, the industry is looking into new technologies, such as green energy sources and circular economy models, to lower its environmental footprint and support sustainable development (Geng et al., 2017; Demetris et al., 2022a; Wang & Lee, 2022; Lai et al., 2022). As sustainability becomes more vital for the semiconductor industry, more research is required on the difficulties and future directions in the semiconductor supply chain (Hervani et al., 2005; Borgman et al., 2013; Awa & Ojiabo, 2016; Demetris et al., 2022b; Mewes & Broekel, 2022). The industry requires research that investigates how to address these challenges and foster sustainable development while considering risks, resilience, and costs (Bridwell & Richard, 1998). Moreover, studies are needed to investigate how sustainability practices affect value creation and financial results in the semiconductor industry (Browning et al., 1995; Lai et al., 2022). It is to be noted that sustainable value creation is a process for creating values for all the stakeholders in a sustainable process. This needs change of business model, value proposition, and modification of value chain system. Such sustainable value creation supports the firms to derive financial, social, and environmental benefits (Lai et al., 2022). Moreover, sustainability initiatives help the organizations to effectively reduce energy consumption and carbon emission which eventually could improve the financial performance of the organizations (Awa et al., 2017). Table 1 provided below narrates the existing studies and gap analysis.

Table 1
Existing studies and gap analysis.

Sources (Authors)	Focus areas of the study	Research/Knowledge/ Literature gap
Browning et al. (1995)	This research demonstrates how to develop cooperation in the semiconductor industry from the competitiveness perspective and advantages out of such collaborations.	This study essentially does not focus on the green supply chain aspects and initiatives of semiconductor industry. Thus, a research gap exists in this study.
Bridwell and Richard (1998)	This research work shows the modern semiconductor industry and its opportunities and challenges. This study follows Michael Porter's industry related approach and related cluster-based operations and competitiveness related issues in semiconductor industry.	This study does not follow any hybrid framework such as TOE-DCV. Neither has this study demonstrated any research model which could be used by organizations to enhance their productivity. Hence, there exists a research gap.
Hervani et al. (2005)	This study thoroughly discussed the performance measurement aspects for green supply chain flow and related issues.	There are a few research gaps in this study as this study does not investigate challenges experienced by the semiconductor industry neither develops any hybrid model or framework such as TAM-TOE or TOE-DCV, and so on.
Awa and Ojiabo (2016)	This study explains different models for the adoption of new technology and related determinants, especially focusing on the enterprise resource planning related applications using the TOE framework.	Although this study discusses technology adoption and the TOE framework, this study is silent on essential dynamic capabilities needed by organizations to successfully adopt green technologies especially by the organizations related to the semiconductor industry. Thus, there are literature gaps in this study.
Geng et al. (2017)	This research project examines the relationship between green supply chain management and performance aspects. This project mostly focuses on the emerging Asian countries.	Although this study highlights different aspects of green supply chain management, the study essentially did not focus much on the semiconductor manufacturing plants and their challenges, clearly showing some research gaps.
Lin et al. (2020)	This study investigates climate risk assessment and the responses of the semiconductor industry. The study focused on applications of TCFD process.	Although this study focused on the semiconductor industry, this research work essentially did not discuss the sustainable supply chain practices in the semiconductor industry. Thus, there is a knowledge gap.
Sueyoshi and Ryu (2021)	This study focuses on environmental assessment and sustainable development practices followed in the US.	The study did not focus on the semiconductor industry nor did the study examine the green practices or initiatives focusing on the supply chain aspect. Thus, there are research gaps.
Van Do et al. (2021)	This study examines the wide-band gap power issue of semiconductors especially focusing on the electric vehicle systems. The study discussed different challenges and current trends.	This study did not investigate any issues related to the supply chain challenges and green initiatives in the semiconductor industry. Hence, there is a research gap.
Frieske and Stieler (2022)	This study has mostly focused on the crisis in the semiconductor industry during COVID-19 pandemic. This study focused on the impact of automative industry and related semiconductor supply chain issues.	Although this study has discussed regarding supply chain flow of semiconductor industry during COVID-19 pandemic focusing on the automative industry, this research is silent about the green initiatives of the semiconductor supply chain

(continued on next page)

Table 1 (*continued*)

Sources (Authors)	Focus areas of the study	Research/Knowledge/ Literature gap
		flow. Thus, this research study has a literature gap.
Wang and Lee (2022)	This study highlighted the impact of clean energy consumption with economic growth. This study focused on China and the regulatory issues.	This study did not describe any challenges and issues experienced by the semiconductor industry. Neither has this study discussed the green initiatives of different semiconductor manufacturing companies. Thus, a research gap exists.
Lai et al. (2022)	This study highlights the strategy for optimal green supply chain financing. This study is focused on internal collaborative financing as well as external investment opportunities.	This study is silent about the green supply chain management opportunities in the semiconductor industry as well as its implementation challenges. Thus, there are clearly some research gaps.

2.2. Theoretical framework and hypotheses development

Various motives for organizations to adopt green practices are discussed in the literature on this topic (Álvarez-Gil et al., 2007; Etzion, 2007; Gadenne et al., 2009). While most studies focus on organizational and external environmental factors regarding GSCM adoption (Li et al., 2011; Zailani et al., 2014), few explore the technological viewpoint. Green supply chain adoption involves applying environmental criteria to reshape operational practices, necessitating innovative approaches to resource utilization, process optimization, and systems enhancement (Hage, 1999; Crossan and Apaydin, 2010; Lai et al., 2022). Developing a framework for innovation adoption in this context requires taking into account factors related to technology, organization, and environment (Lin, 2014). This study applies the Technology-Organization-Environment (TOE) framework (Tornatzky et al., 1990) and modifies it to explore the adoption of green supply chains, providing a holistic view and theoretical direction for analysing influential factors in the semiconductor industry. It is worth mentioning that the TOE framework is a theoretical framework that describes how organizations adopt and use technological innovations, and how the technological context, organizational context, and environmental context affect this process. The TOE framework is a theoretical model that looks at how organizations adopt technology and how the adoption and use of technological innovations are influenced by the technology context, organization context, and environment context. The dynamic nature of semiconductor markets necessitates organizations to enhance their dynamic capabilities to meet evolving market demands. A useful way to make sense of and explain this complicated situation is the dynamic capability view (DCV) that Teece et al. (1997) suggested. The TOE framework is a conceptual framework that emerged in the field of information systems to show how different factors affect the adoption and use of new technologies (Hwang et al., 2016). This framework consists of the features of the technology itself, the organizational setting in which it is applied, and the external business environment in which the organization functions (Chatterjee et al., 2021). Also, the TOE framework advocates that for adoption of new technologies by different organizations in a high velocity market environment, the organizational dynamic capabilities are required to be improved (Abdurrahman et al., 2024). This idea is argued to have invited the need to integrate the concepts of DCV along with the TOE framework to explain how different factors could successfully adopt GSCM practices in the semiconductor industry.

Winter (2003, p. 991) conceptualized DCV as "high-level routine (or collection of routines) that, together with its implementing input flows, confers upon an organization's management a set of decision options for producing significant outputs of a particular type". Scholars regard organizational capabilities as sought-after attributes for firms (Schreyögg and KlieschEberl, 2007). A clear classification in the literature separates normal capabilities and dynamic capabilities (Winter, 2003; Teece, 2012). Dynamic capabilities, integral to contemporary supply chain management paradigms, shape how effectively an organization leverages existing capabilities when acquiring new knowledge or developing additional competencies, thereby contributing to competitive advantage. Basic capabilities, which are associated with firm's resources (Pezeshkan et al., 2016; Awa et al., 2017), are defined by their strong incorporation into firm practices to improve operational efficiency. These capabilities cover various functions, such as operational, administrative, and governance-related activities (Teece, 2014). It is to note that the notion of dynamic capabilities has some resemblance to the older concept of operational capabilities; the latter relates to the present activities of an organization, while the former, on the other hand, denotes an organization's ability to modify these activities and enhance its resources effectively and adaptability.

2.2.1. Technological risks related issues

The companies that design and develop new chips, either by themselves or with partners, are known as "fabless" companies. They have this name because they do not make the chips that they design and sell (Li et al., 2011; Wang et al., 2023). The foundries are dedicated plants that produce the semiconductor chips. Design of the chips are obtained from the fabless companies, and specialized machinery is employed to fabricate and imprint chips onto a silicon wafer (Bridwell & Richard, 1998; Awa & Ojiabo, 2016). There are various kinds of technological risk involves in GSCM process of semiconductor industry. Risks to the green supply chain are unexpected events that could impact the green or eco-friendly movement of materials and disrupt the planned flow of green materials and products from where they start to where they are used in business (Ortega et al., 2007; Li et al., 2011; Teece, 2014b; Sheshadri, 2019; Feng et al., 2022). Additionally, technological risks could include technological disruption in the supply chain flow due to new technological breakthroughs (Oliveira et al., 2019; Mukherji & Silberman, 2021). The financial and human capital risks pose impediments towards smooth implementation of GSCM in the semiconductor industry. Producing chips has become more expensive because of the high prices of the parts. Moreover, for implementing GSCM, the semiconductor industry needs more skilled human resources which are scant. Again, lack of technological compatibility is perceived to have adversely affected the adoption of any new technology in organizations. In this context, it is to note that compatibility is a term that describes how software and hardware from different origins can function together without needing any changes to make them do so (Ortega et al., 2007; Mukherji & Silberman, 2021). Furthermore, the green supply chain flow could face risk from the complexity of its processes and the technological alignment of different systems of suppliers and producers in the semiconductor industry. This concept agrees with the notion of TOE framework that looks at how organizations adopt technologies. It is essential to note that technological turbulence is conceptualized as rate of technological advancement within an industry (Song et al., 2005; Wang et al., 2023). Technological complexity refers to the required technological level for the creation and production of an industrial product, based on its features and functions (Awa et al., 2017; Oliveira et al., 2019). The TOE framework could show how technological, organizational, and environmental context influence the adoption of new technologies in organizations (Tornatzky et al., 1990). Thus, it seems that technological turbulence and risks, technological complexity, as well as lack of technological compatibility might have some adverse impacts towards the adoption of GSCM process in the semiconductor industry. Therefore, the above discussion leads to the following hypotheses.

H1a. Technological turbulence and risk (TTR) negatively impacts GSCM adoption in the semiconductor industry (GSCS).

H1b. Technological complexity (TEC) negatively impacts GSCM adoption in the semiconductor industry (GSCS).

H1c. Lack of technological compatibility (TCO) negatively impacts GSCM adoption in the semiconductor industry (GSCS).

2.2.2. Organizational dynamic capabilities and resilience

Many studies have suggested that proactive GSCM practices are important (Stekelorum et al., 2021), such as working with suppliers or taking part in early supplier involvement programs to create eco-friendly products (Srivastava, 2007; Tseng et al., 2019; Sheshadri, 2021). By adopting green management, firms can also achieve lean management, which can help them improve their performance (Teece, 2014a; Stekelorum et al., 2021). To achieve this integration, the participation of suppliers in GSCM practice is essential. Moreover, studies have indicated that resource reconfiguration capability is a key factor for effective GSCM. The GSCM process interacted with the changing sustainability requirements and the dynamic environmental conditions in a constant and flexible way (Teece et al., 1997; Singh, 1997; Awa & Ojiabo, 2016). Many scholars agree that the dynamic capabilities (DCs) perspective and GSCM are related because of the comparable organizational situations. Dynamic resilience capability is the ability that allows organizations to thrive in turbulent environments (Teece et al., 1997; Chowdhury & Quaddus, 2017). The goal of these studies was to show how firms can gain an edge in a dynamic environment (Geng et al., 2017; Stekelorum et al., 2021; Vrontis et al., 2022b). The market for semiconductor related businesses is changing fast and to cope with such changes, the organizations need to build their dynamic capabilities to perceive, capture, and adapt the internal and external opportunities to achieve better competitive advantage. This concept corroborates the theme projected in DCV (Teece et al., 1997).

The semiconductor industry relies on dynamic capabilities throughout the chip production process, encompassing manufacturing, testing, and distribution via the organization's supply chain management system (Stekelorum et al., 2021). Different vendors assume specific roles at various stages within the semiconductor SCM system. The effectiveness of the overall supply chain management system is significantly influenced by the dynamic capabilities exhibited by these vendors (Bridwell and Richard, 1998). Semiconductor chips go through testing and assembly at the semiconductor production plant after they are made. Their functionality needs to be verified before they are used. This is usually done by different companies that focus on testing and assembly (Li et al., 2011). The packaged chips meeting requisite standards undergo assembly to create products suitable for use in electronic devices. Subsequently, these products are distributed either directly to end customers or integrated into other products by companies, either through direct sales or intermediary distributors (Bridwell and Richard, 1998; Thrassou et al., 2021). A supply chain that can resist and recover from disruptions is resilient. This means having the ability to prevent or reduce most supply chain problems and minimize the damage of those that happen. The organizational dynamic innovation capability could support from the recovery of such disasters (Li et al., 2011). A firm's innovation capability is its skill to find new ideas and turn them into new and improved products, services or processes that help the firm (Chatterjee, 2015; Elia et al., 2020; Feng et al., 2022). Supply chain resilience can also support to manage operational risk and interruption that could affect various parts of the supply chain, and ultimately could harm business resiliency and organizational dynamic competitiveness. Organizational dynamic competitiveness means how well an organization can achieve a better position in the volatile market and maintain its position for a long time in industry (Hitt et al., 1994; Teece et al., 1997). Global events like COVID-19 pandemic can cause widespread, international effects on supply chain logistics, suppliers, and workforces, especially for the semiconductor GSCM process (Geng et al., 2017; Stekelorum et al., 2021). Thus, it is perceived that dynamic resilience capability, innovation ability, and organizational dynamic competitiveness may have some influence on the adoption of GSCM practices in the semiconductor industry. The above discussion helps to formulate the following hypotheses.

H2a. Dynamic resilience capability (DRC) positively impacts GSCM adoption in the semiconductor industry (GSCS).

H2b. Innovation capability (INC) positively impacts GSCM adoption in the semiconductor industry (GSCS).

H2c. Organizational dynamic competitiveness (ODC) positively impacts GSCM adoption in the semiconductor industry (GSCS).

2.2.3. Govt. Policy and regulation in semiconductor industry

The world economy largely depends on the semiconductor industry. It has contributed to a lot of technological innovation, economic development, and employment for many countries (Flamm & Reiss, 1993). It also has to follow the rules of both national governments and international groups like the world trade organization. Hence, every government needs to articulate appropriate policy comprehensively so that firms navigating the businesses in the context of the semiconductor industry may not feel any unnecessary constraint domestically as well as internationally. Thus, the policy should be flexible and in consonance with WTO (Khan et al., 2021). Regulations affect the industry in every way, from prices to technological progress (Assimakopoulos et al., 2003; Almeida et al., 2010; Hwang et al., 2016; Elia et al., 2020). Semiconductor companies may be pushed to adopt certain behaviours by coercive pressures, such as legal sanctions or threats (Meyer & Rowan, 1977). Environmental factors force firms to join in sustainability efforts, influenced by the threat of new environmental rules or clear governmental backing for sustainable practices (Singh et al., 1990; Mousavi et al., 2019; Demetris et al., 2022; Ratusny et al., 2022). These official methods are norms, rules, processes, and rewards that regulatory bodies use to motivate firms to be environmentally conscious. Additionally, a semiconductor company may have a sense of social responsibility based on what society expects, values, and prescribes (Jones, 1999).

Historically, the corporate network of firms, encompassing ecological entities, communal organizations, and diverse stakeholders, was commonly perceived as non-supportive and often overlooked, exerting minimal influence on firm performance (Henriques and Sadorsky, 1999; Watterson, 2006; Wang and Chiu, 2014; Kim et al., 2014; Khan et al., 2021). Also, having the relevant customer and vendors in a specific location with favorable government policy and regulations could be crucial for the semiconductor industry (Irwin, 1996; Ouyang, 2006; Prosser, 2010). Besides, more availability of customers should ensure better profitability rendering the organizations more financially stable. This would support the organization to ensure better adoption of GSCM since such initiatives needs financial support. All these issues combined could seriously affect the implementation of GSCM practices by semiconductor industry. Thus, it is perceived that government policy and regulations along with the influence of social community might have substantial impacts on the adoption of GSCM in the semiconductor industry. The above discussion helps to put together the following hypotheses.

H3a. Government policy (GOP) positively impacts GSCM adoption in the semiconductor industry (GSCS).

H3b. Government regulation (GOR) positively impacts GSCM adoption in the semiconductor industry (GSCS).

H3c. Influence of social community (SOC) positively impacts GSCM adoption in the semiconductor industry (GSCS).

H3d. Customer availability (CUA) positively impacts GSCM adoption in the semiconductor industry (GSCS).

All the above discussion including theories help to formulate the following theoretical model shown in Fig. 1.

3. Research methodology

To validate the model, the survey method has been followed. Be it

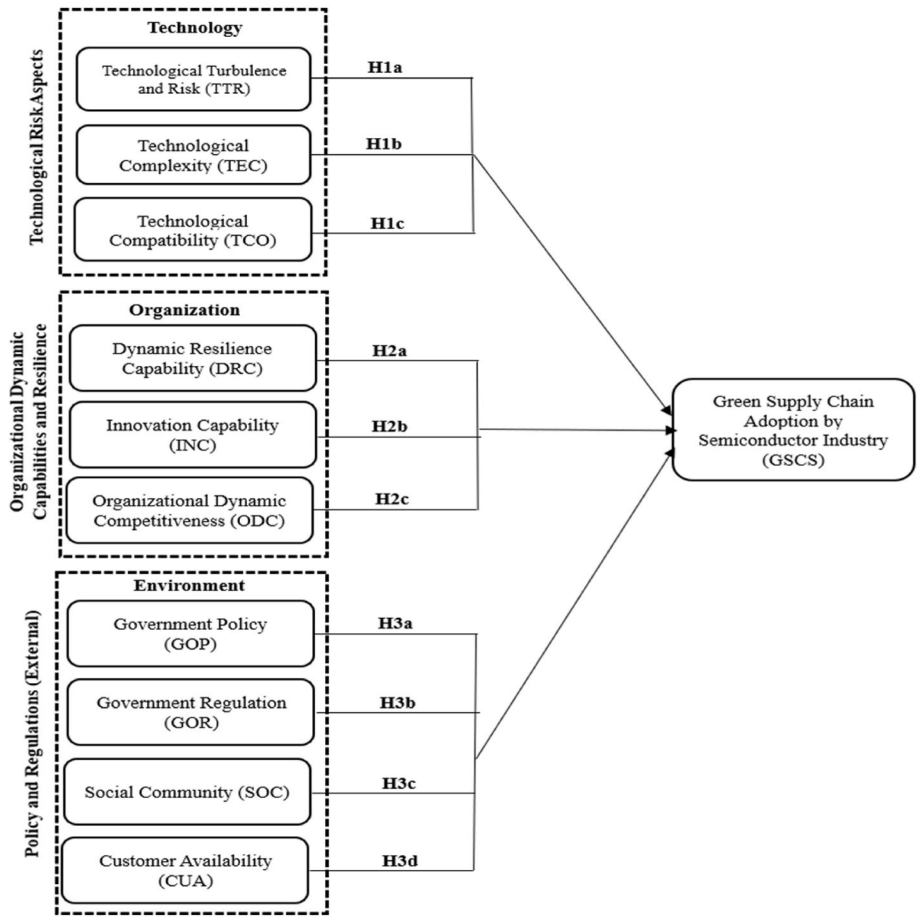

Fig. 1. The theoretical model. (adopted from TOE and DCV).

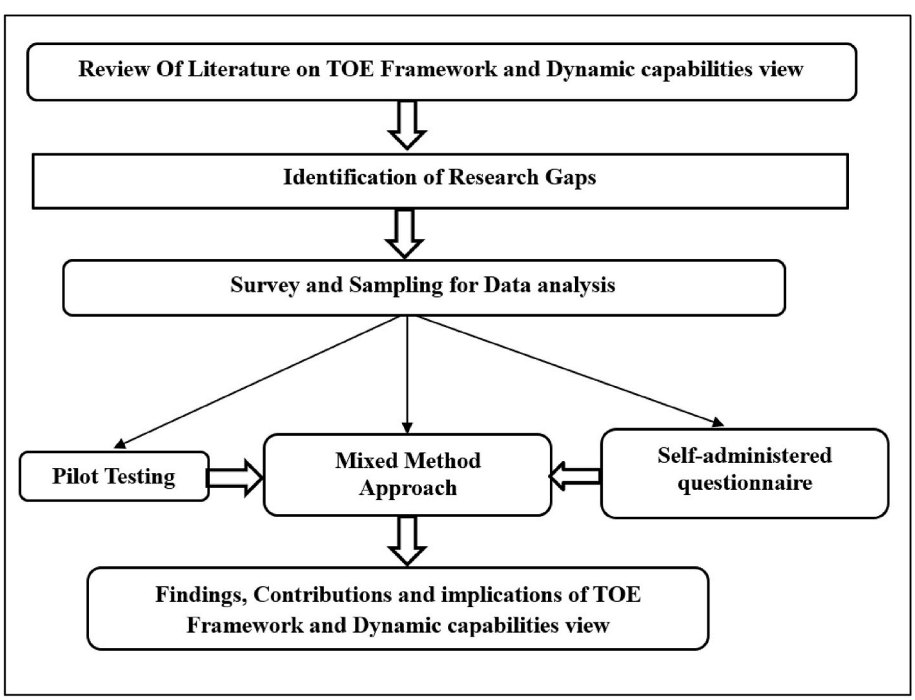

Fig. 2. Schematic diagram of research study.

mentioned here, for validation of the conceptual model, survey approach is perceived to be advantageous because this approach is less expensive and faster, easy to implement, more accurate than interpreting behavior data, easy to obtain quantitative feedback, and so on (Lazaraton, 2005). For this, feedback of the respondents is to be analysed. For obtaining the feedback, appropriate instruments have been articulated taking support of extant literature and theories. Purposive and convenience sampling techniques have been applied to target the respondents. It is to note that here purposive sampling technique has been used because this technique has multiple phases for comprehensive insights, it is associated with maximum variation for in-depth analysis, this technique has less margin of error, as well as this technique could save time and money for collection of data. Besides, convenience sampling techniques have also been used as this technique can help to quickly collect data, the approach is not expensive, and easier to implement. These advantages are not extensively available for the other sampling processes. To validate the proposed hypotheses, survey method has been followed. This method is considered suitable for such studies that have the specific goals of testing the hypotheses, describing the population accurately, explaining the measurement scales clearly, and building the research framework (Lee and Shim, 2007). The entire flow of the research study is highlighted briefly through a schematic diagram (Fig. 2).

The next sections describe the questionnaire development and the data collection process with non-response bias.

3.1. Research instruments

After reviewing the existing literature, a set of questions as statements was developed. The recitals of the instruments in the form of statements have duly been updated commensurate with the context of the present study. All these statements were pretested by asking the opinion of the experts. For this, twelve experts were consulted. Among the twelve experts involved in the study, half were industry professionals with expertise in the electronic and hi-tech sector, providing valuable insights relevant to the study. The remaining six experts represented academia, possessing substantial knowledge and expertise within the specific research area under investigation. These experts' valuable views made the questions simpler and clearer. This process fixed the questions' wording so that the possible respondents could answer them easily. Later, a pilot test was done using responses from 50 participants who were chosen through convenience sampling. Analysis of the feedback from this group facilitated enhancements to the comprehensibility, readability, and clarity of all survey questions. It is to note that the pre-test is a process of using the feedback from experts to improve and refine how clear, readable, and understandable all the survey questions are. A pilot test was also conducted to check the reliability and validity of constructs and to remove some unsuitable questions to ensure the quality of instruments. It is pertinent to mention here that pilot study is a study with small samples to test and modify the recitals of the instruments. Such a study helps to identify the problem areas and suggests the feasibility of the full-scale study to be conducted later. In the present study, the pilot study has been conducted to analyse the responses of 50 participants who were selected through the convenience sampling technique and this analysis in the pilot test helped to facilitate the enhancement of readability, clarity, and comprehensiveness of the survey instruments. Consequently, 39 refined questions can be seen in Appendix A as statements related to the constructs.

3.2. Sample collection

The sample of the study consisted of electronics and hardware industries in India, the data were gathered by initially reaching out to various business associations, including Confederation of Indian Industry, Federation of Indian Chambers of Commerce & Industry and so on through questionnaire survey. In order to ensure the efficacy of the questionnaire, a pilot study was first conducted, eliciting responses from 50 participants chosen through convenience sampling. The objective was to establish contact with individuals linked to this industry and policymakers. With the support of these industry associations, 732 organizations were targeted including small and micro- organizations, midsized organizations, and large organizations related to electronics and hardware industry. For the collection of data, mixed method approach was used which include online data collection through Google form, in person feedback collection, as well as using reference to collect data. A survey packet was comprised of a cover letter (consisting of the study objectives, the confidentiality certitude, and the request for participation), and the questionnaire was circulated with each participant. The data collection method employed for the field study utilized a self-administered questionnaire, resulting in a response rate of 50.81%. Following careful examination, 16 incomplete responses were excluded from the analysis. The subsequent data analysis was conducted with a final sample size of 356 respondents. Table 2 provides a breakdown of participant details.

3.3. The non-response bias

To check for non-response bias, the answers of the first and last 100 participants were compared using the methods of Armstrong and Overton (1977), which involved chi-square and independent t-tests. The comparison did not reveal any significant differences, indicating that non-response bias was not a problem in the data.

4. Analysis of data

The responses from 356 participants were assessed using a Likert scale on the range of 1–5, where 1 represents Strongly Disagree (SD) and 5 represents Strongly Agree (SA). Here, a five-point Likert scale has been used to quantify the responses of the 356 respondents. This scale has been chosen because this 5-point Likert scale is simple to apply and at the same time this scale provides an opportunity for the respondents to take a neutral stand by providing 'nor disagree nor agree' option. Subsequently, the collected data underwent analysis using the PLS SEM technique. This method can analyse data with a simple approach (Akter et al., 2011). This method can also analyse data that is not normally distributed (Sarstedt et al., 2014). Also, this technique does not have any sample restriction (Akter et al., 2017). Because of these benefits, analysis of data has followed the PLS-SEM technique.

Table 2
Details of respondents (N = 356).

Particulars	Category	Number	Percentage
Organization size	Large (>500m USD annual revenue)	160	44.9
	Midsized organizations (100–500m USD annual revenue)	106	29.8
	Small and micro-organizations (<100m USD annual revenue)	90	25.3
Organization age	Older organizations (>25 years of establishment)	142	39.9
	Younger organizations (5–25 years of establishment)	117	32.9
	Startups/recently established organizations (<5 years of establishment)	107	27.2
Respondents' designation	Senior managers (>15 years of managerial experience)	78	21.9
	Midlevel manager (5–15 years of managerial experience)	135	37.9
	Junior managers (<5 years of managerial experience)	143	40.2

Table 3
Measurement properties.

Constructs/Items	LF	AVE	CR	α	t-value
TTR		0.833	0.952	0.934	
TTR1	0.889				8.632
TTR2	0.911				10.630
TTR3	0.921				11.656
TTR4	0.930				14.373
TEC		0.737	0.897	0.879	
TEC1	0.870				18.854
TEC2	0.910				25.704
TEC3	0.906				22.436
TEC4	0.737				11.305
TCO		0.806	0.921	0.920	
TCO1	0.870				26.342
TCO2	0.909				27.639
TCO3	0.921				35.431
TCO4	0.891				23.540
DRC		0.769	0.851	0.850	
DRC1	0.867				23.931
DRC2	0.890				28.418
DRC3	0.874				22.535
INC		0.713	0.867	0.865	
INC1	0.874				25.764
INC2	0.878				26.672
INC3	0.842				21.493
INC4	0.780				21.247
ODC		0.736	0.881	0.880	
ODC1	0.823				26.087
ODC2	0.876				26.030
ODC3	0.856				32.810
ODC4	0.875				26.433
GOP		0.726	0.818	0.810	
GOP1	0.797				19.568
GOP2	0.880				24.170
GOP3	0.877				21.147
GOR		0.670	0.755	0.755	
GOR1	0.800				15.995
GOR2	0.837				17.314
GOR3	0.819				19.621
SOC		0.719	0.808	0.805	
SOC1	0.841				20.015
SOC2	0.872				20.886
SOC3	0.830				21.519
CUA		0.753	0.842	0.836	
CUA1	0.824				17.925
CUA2	0.891				21.980
CUA3	0.888				22.785
GSCS		0.698	0.856	0.856	
GSCS1	0.845				30.586
GSCS2	0.826				29.374
GSCS3	0.843				26.255
GSCS4	0.827				28.323

4.1. Different parameters with estimation

This study followed a series of steps to validate the research model that it proposed. First, an evaluation was performed to check the reliability of the constructs, and the convergent and discriminant validity, using the established model. Table 3 shows the values for construct reliability, including Cronbach's alpha and composite reliability (CR). For the concept of convergent validity, the average variance extracted (AVE) was also computed. All results surpassed the recommended minimum of 0.5, indicating their adequacy (Hair et al., 2017). Table 3 displays the results.

4.2. Test for discriminant validity

This section shows the construct correlation matrix, where the diagonal is the square root of the AVE. We followed the method suggested by Fornell and Larcker (1981), in which we compared the AVE for each construct with the shared variance, shown by the squared correlation, among the constructs (Farrell, 2010). In this method, the AVE values are higher than the squared correlations between the components, thus confirming discriminant validity as seen in Table 4.

Moreover, we applied the heterotrait-monotrait ratio of correlations (HTMT) as suggested by Henseler et al., (2015). The HTMT values that we got were lower than the threshold of 0.85, as stated by Franke and Sarstedt (2019) showing enough evidence of discriminant validity, as displayed in Table 5.

4.3. Calculation of the effect size f^2

To assess the impact of exogenous variables on related endogenous variables, we conducted an effect size f^2 test. According to Cohen (1988), f^2 values are categorized as weak (W) if they fall between 0.020 and 0.150, moderate (M) between 0.150 and 0.350, and large (L) when they exceed 0.350. The effect size f^2 test values are displayed in Table 6.

4.4. Comprehensive robustness checks

The robustness of our model is affirmed through comprehensive analyses, unveiling positive linear relationships and successful endogeneity outcomes. Employing SmartPLS, we systematically assessed quadratic effects, demonstrating the model's resilience across diverse scenarios. The Gaussian Copula analysis further bolsters robustness, adeptly capturing intricate dependencies. Aligning with best practices as outlined by Sarstedt et al. (2014) in Tourism Economics, our methodology adheres to established norms in PLS-SEM, fortifying the credibility of our findings. Collectively, these results underscore the model's reliability and stability, emphasizing its capacity to endure variations and uncertainties effectively. Table 7 shows the results.

4.5. Testing of hypotheses and structural equation model

A bootstrapping technique with 5000 resamples was employed to test our model. Cross-validated model redundancy was utilized a distinct measure with a threshold of 7, yielding a positive Q2 value that confirms

Table 4
Discriminant validity test (Fornell and Larcker criteria).

Construct	CUA	DRC	GOP	GOR	GSCS	INC	ODC	SOC	TCO	TEC	TTR	AVE
CUA	0.868											0.753
DRC	0.640	0.877										0.769
GOP	0.474	0.533	0.852									0.726
GOR	0.569	0.560	0.570	0.819								0.670
GSCS	0.672	0.685	0.654	0.704	0.835							0.698
INC	0.581	0.650	0.653	0.730	0.759	0.844						0.713
ODC	0.628	0.633	0.615	0.672	0.781	0.729	0.858					0.736
SOC	0.510	0.503	0.580	0.582	0.676	0.634	0.614	0.848				0.719
TCO	−0.521	−0.505	−0.479	−0.510	−0.625	−0.553	−0.567	−0.505	0.898			0.806
TEC	−0.383	−0.448	−0.393	−0.436	−0.526	−0.470	−0.446	−0.412	0.495	0.858		0.737
TTR	−0.172	−0.194	−0.147	−0.144	−0.279	−0.184	−0.210	−0.161	0.231	0.142	0.913	0.833

Note: Diagonal = $\sqrt{\text{AVE}}$.

Table 5
Discriminant validity test (HTMT).

Construct	CUA	DRC	GOP	GOR	GSCS	INC	ODC	SOC	TCO	TEC	TTR
CUA	–										
DRC	0.757	–									
GOP	0.573	0.642	–								
GOR	0.719	0.695	0.727	–							
GSCS	0.794	0.802	0.783	0.842	–						
INC	0.684	0.758	0.783	0.839	0.842	–					
ODC	0.730	0.732	0.727	0.824	0.800	0.834	–				
SOC	0.621	0.607	0.718	0.745	0.813	0.758	0.728	–			
TCO	0.593	0.570	0.554	0.611	0.704	0.620	0.631	0.586	–		
TEC	0.446	0.513	0.461	0.529	0.602	0.537	0.504	0.481	0.544	–	
TTR	0.191	0.215	0.166	0.170	0.306	0.199	0.231	0.181	0.245	0.158	–

Table 6
Computation of effect size f^2.

Construct	GSCS
CUA	0.033
DRC	0.022
GOP	0.018
GOR	0.020
INC	0.023
ODC	0.086
SOC	0.040
TCO	0.015
TEC	0.018
TTR	0.030

the model's predictive relevance. Model fit was assessed using the standardized root mean square residual (SRMR), yielding values of 0.062 for PLS and 0.033 for PLSc (Henseler et al., 2014). Given that these values are below the prescribed threshold of 0.08, it indicates the satisfactory performance of the model, as per the criteria outlined by Hu and Bentler (1999). Also, for assessing the model fit, standard measures have been taken which highlight that the estimated values of ratio of chi-square and the degree of freedom, comparative fit index, and normal fit index are all within the specified range. Applying SEM enabled the determination of path coefficients and their associated p-values for all linkages. Additionally, the model's ability to predict has been determined. Table 8 shows the results.

4.6. Common method bias (CMB)

It is seen that the result of the present study principally depends on the data which has been collected through the survey method. Hence, the chance of existence of CMB in responses of the respondents cannot be avoided. As such, initially, some procedural measures were taken to minimize CMB. The recitals of the questions were made simpler through pretest as well as through pilot test. Also, the respondents concerned were assured that their anonymity and confidentiality will be strictly preserved. These were done to ensure the responses without any bias. Also, to check the severity of CMB, Harman's Single Factor Test (SFT) was conducted. The result highlighted that the value of first variance was far below 50% which is the recommended highest value (Podsakoff et al., 2003). Since Harman's SFT is criticized as not a robust and conclusive test for detection of CMB as observed by Ketokivi and Schorder (2004), marker correlation ratio test was also conducted (Lindell and Whitney, 2001). This test also did not show any evidence of CMB. Hence, it is confirmed that the CMB could not pose a major threat in the present study.

5. Results and discussion

Ten hypotheses were developed in the present study and later on tested using the PLS-SEM approach. The results indicate that TTR, TEC, and TCO have significant and negative effects on GSCS, supported by path coefficients of −0.084, −0.077, and −0.078, respectively. Furthermore, present study underscores the positive impact of DRC, INC, and ODC on GSCS, with respective $\beta = 0.106$, 0.131, and 0.236. This study establishes a positive and statistically significant influence of GOP, GOR, SOC, and CUA on GSCS. The path coefficients for these relationships are 0.090, 0.105, 0.134, and 0.125, respectively. Regarding the coefficient of determination (R^2), our findings indicate that TTR, TEC, TCO, DRC, INC, ODC, GOP, GOR, SOC, and CUA collectively exhibit a predictive capacity of 77% ($R^2 = 0.77$) for GSCS. This represents the comprehensive predictive strength of the proposed theoretical model. This is to note that from the study of extant literature and from the TOE-DCV, three hypotheses H1a, H1b, and H1c have been formulated to demonstrate that technological issues like risks, reliance, and complexity could impact GSCM practices in the semiconductor industry. These three hypotheses have duly been validated through PLS-SEM technique addressing thereby RQ1. Again, formulating H2a, H2b, and H2c from the inputs of literature and theories, it is demonstrated that dynamic capabilities of the organizations could affect adoption of GSCM in the semiconductor industry. These hypotheses were duly supported as they have been successfully tested by PLS-SEM technique, addressing thereby RQ2. Also, the impacts of government policies and regulations towards the adoption of GSCM in the semiconductor industry have duly been elucidated through formulation of hypotheses H3a and H3b which were also subsequently validated by PLS-SEM technique, addressing thereby RQ3. All these aspects have duly been discussed in section 2, section 3, and section 4 in detail.

This study establishes that the adoption of a Green Supply Chain Management (GSCM) system in the semiconductor industry qualifies as a distinctive form of green innovation. This categorization is attributed to the incorporation of both green practices and industrial ecology within the GSCM framework. While exploring such adoption of GSCM system in semiconductor industry, TOE framework and DCV concept are leveraged in the study. While Hwang et al. (2016) previously elucidated the adoption of GSCM systems in the semiconductor industry using only the TOE framework, our study extends this exploration by incorporating the DCV for a more comprehensive analysis. This study has demonstrated that the concept of ensuring sustainability in any industry surpasses corporate policy and existing regulations as well as reflects the increate dynamism of GSCM system. In such a perspective, the aim of this present study is to develop a pragmatic and holistic decision-making framework helpful for ensuring successful adoption of GSCM system in the semiconductor industry through the proper identification of series of appropriate consideration of factors like risk and resilience with their causal relationship. The framework relies primarily on the Technology-Organization-Environment (TOE) framework, complemented by the concept of Dynamic Capabilities View (DCV). Notably, various studies assert that the competitive advantage of adopting GSCM system in the industry is contingent on the decisions made by the relevant industrial authorities (del Río González, 2005; Etzion, 2007; Robinson & Stubberud, 2013). However, the present study has

Table 7
Gaussian copula analysis results using SmartPLS.

Statistical test	Targeted construct	Estimated coefficient	p- value
Gaussian copula of model 1 (endogenous variables; INC)	GC (INC) → GSCS	−0.154	0.062
Gaussian copula of model 2 (endogenous variables; DRC)	GC (DRC) → GSCS	−0.121	0.090
Gaussian copula of model 3 (endogenous variables; ODC)	GC (ODC) → GSCS	−0.191	0.053
Gaussian copula of model 4 (endogenous variables; INC, DRC)	INC (c); DRC (c)	−0.134–0.107	0.086 0.101
Gaussian copula of model 5 (endogenous variables; INC, ODC)	INC (c); ODC (c)	−0.123–0.152	0.120 0.085
Gaussian copula of model 6 (endogenous variables; DRC, ODC)	DRC (c); ODC (c)	−0.105–0.109	0.092 0.072
Gaussian copula of model 7 (endogenous variables; INC. DRC, ODC)	INC (c); DRC (c); ODC (c)	−0.127–0.095 -0.11	0.059 0.103 0.234
Gaussian copula of model 8 (endogenous variables; GOP)	GC (GOP) → GSCS	0.014	0.797
Gaussian copula of model 9 (endogenous variables; GOR)	GC (GOR) → GSCS	−0.162	0.068
Gaussian copula of model 10 (endogenous variables; CUA)	GC (CUA) → GSCS	−0.114	0.201
Gaussian copula of model 11 (endogenous variables; SOC)	GC (SOC) → GSCS	−0.043	0.446
Gaussian copula of model 12 (endogenous variables; GOP, GOR)	GOP (c); GOR (c)	0.015 −0.162	0.801 0.109
Gaussian copula of model 13 (endogenous variables; GOP, CUA)	GOP (c); CUA (c)	0.018–0.115	0.772 0.201
Gaussian copula of model 14 (endogenous variables; GOP, SOC)	GOP (c); SOC (c)	0.016–0.043	0.782 0.444
Gaussian copula of model 15 (endogenous variables; GOR, CUA)	GOR (c); CUA (c)	−0.156–0.109	0.510 0.002
Gaussian copula of model 16 (endogenous variables; GOR, SOC)	GOR (c); SOC (c)	−0.160–0.036	0.099 0.512
Gaussian copula of model 17 (endogenous variables; CUA, SOC)	CUA (c); SOC (c)	−0.113 −0.037	0.081 0.493
Gaussian copula of model 18 (endogenous variables; GOP, GOR, CUA, SOC)	GC (GOP) → GSCS GC (GOR) → GSCS GC(CUA) → GSCS GC(SOC) → GSCS	−0.018 −0.153 −0.108 −0.031	0.722 0.212 0.062 0.560
Gaussian copula of model 19 (endogenous variables; TEC)	GC (TEC) → GSCS	0.03	0.599
Gaussian copula of model 20 (endogenous variables; TTR)	GC (TTR) → GSCS	0.078	0.212
Gaussian copula of model 21 (endogenous variables; TCO)	GC (TCO) → GSCS	0.052	0.299
Gaussian copula of model 22 (endogenous variables; TEC, TTR)	TEC (c); TTR (c)	0.027 0.077	0.636 0.219
Gaussian copula of model 23 (endogenous variables; TEC, TCO)	TEC (c); TCO (c)	0.019 0.049	0.748 0.341
Gaussian copula of model 24 (endogenous variables; TTR, TCO)	TTR (c); TCO (c)	0.074 0.048	0.240 0.338
Gaussian copula of model 25 (endogenous variables; TEC, TTR, TCO)	TEC (c); TTR (c); TCO (c)	0.045 0.017 0.073	0.378 0.774 0.242
Gaussian copula of model 26 (endogenous variables; INC, DRC, ODC, GOP, GOR, CUA, SOC, TEC, TTR, TCO)	INC (c); DRC (c); ODC (c); GOP (c); GOR (c); CUA (c); SOC (c); TCO (c); TTR (c); TEC (c)	−0.078–0.098 -0.104 0.043–0.109 -0.064–0.031 0.015 0.002 0.071	0.146 0.083 0.138 0.401 0.070 0.088 0.559 0.204 0.974 0.742

Table 8
Structural equation modelling.

Linkages	Hypotheses	Path coefficients	Sign	p-values	Remarks
TTR→GSCS	H1a	0.084	Negative	0.001	Supported
TEC→GSCS	H1b	0.077	Negative	0.025	Supported
TCO→GSCS	H1c	0.078	Negative	0.040	Supported
DRC→GSCS	H2a	0.106	Positive	0.020	Supported
INC→GSCS	H2b	0.131	Positive	0.025	Supported
ODC→GSCS	H2c	0.236	Positive	0.000	Supported
GOP→GSCS	H3a	0.090	Positive	0.026	Supported
GOR→GSCS	H3b	0.105	Positive	0.018	Supported
SOC→GSCS	H3c	0.134	Positive	0.019	Supported
CUA→GSCS	H3d	0.125	Positive	0.001	Supported

demonstrated that adoption of GSCM system in the semiconductor industry becomes highly effective for the industry especially when there exists high degree of compatibility by improving organizational dynamic capabilities, by developing appropriate policy and regulations, as well as by lowering the technological complexities. The study underscores the importance of viewing the green supply chain as a potent innovation that goes beyond conventional sustainability initiatives. It enhances environmental practices across the semiconductor industry's supply chain, specifically addressing and mitigating the environmental impacts associated with semiconductor embedded products throughout their entire lifecycles. By using TOE framework, this study has developed a model which highlights that technological hazard retard adoption of GSCM, but the organizational dynamic abilities and appropriate policy supported by executable regulation could help the semiconductor industry to adopt GSCM system successfully by mitigating risks and improving their resilience.

6. Implications

6.1. Theoretical contributions

The present research work has demonstrated how technological complexities and risks could impede adoption of GSCM processes, how such adoption is facilitated by the enhanced dynamic capabilities, and resilience of the semiconductor industry, and how adherence to existing policies and regulations could support the semiconductor industry to adopt GSCM process. This study's uniqueness lies in its comprehensive examination of key issues impacting the semiconductor industry's adoption of GSCM practices for enhanced sustainability. No other known studies have simultaneously addressed and analysed these important issues to the same extent. This research has shown how technological difficulties and hazards could hinder the implementation of GSCM processes, how such implementation is enabled by the improved dynamic capabilities and resilience of the semiconductor industry, and how existing policies and regulations could help the semiconductor industry to adopt GSCM process. The distinctiveness of this study is in its thorough analysis of main issues affecting the adoption of GSCM practices by the semiconductor industry for increased sustainability.

While exploring factors influencing the adoption of GSCM practices in the semiconductor industry, the present study has taken help of integrated concepts of TOE framework and DCV. This combined framework enhances the elucidation of GSCM system adoption dynamics within the semiconductor industry. The study successfully applied the extended aspects of the TOE framework and DCV, representing a noteworthy theoretical contribution. This is because other studies have investigated how adoption of GSCM system could help the industries, but these studies did not deal with the issue especially for the semiconductor industry. This study is principally involved in discussing the prospect of adoption of GSCM process in semiconductor industry with consideration of critical issues like risk and resilience. Hence, to interpret the affairs of such adoption, this study could have taken help of a standard adoption model in a simplified manner. But this study did not do that.

In contrast, the study has not only identified more suitable factors influencing such adoption but has also successfully developed a theoretical model with robust explanatory power, constituting an additional theoretical contribution. A study of Hwang et al. (2016) demonstrated how it was possible to explain implementation of green supply chain flow in the semiconductor industry. This concept has been extended in the present study to explain how TOE framework and DCV concept could explicitly explain the successful adoption of GSCM in the semiconductor industry in a more comprehensive manner. This augmentation contributes valuable insights, enhancing the existing literature.

6.2. Practical implications

The present study has several useful applications if the study findings can be suitably generalised. As per the present research work, it is found that several technological risk aspects such as turbulence in modern technologies, technological complexities, as well as lack of technological compatibility negatively influence adoption of GSCM system in the semiconductor industry. This implies that the leaders and managers of the semiconductor industry should be careful and fully aware regarding the risks associated with use of modern technologies. Additionally, such findings also highlight that use of technologies sometimes creates constraints for the organizations to adopt GSCM system. This means that leaders of the semiconductor industry need to monitor that the workers of the organizations are well-informed about the daily progress of the technologies so that the technological instability and challenges do not prevent the implementation of GSCM practices. The leaders of the semiconductor and electronics industry should ensure that the designers simplify the technological applications to avoid any difficulties for any employees to use modern technologies for implementing GSCM system in the semiconductor and electronics hardware industry. In addition, the leaders should provide adequate training to the employees to help them become proficient in using the modern technologies comfortably. Furthermore, this study has highlighted that organizational dynamic capabilities and resilience which include innovative capabilities, dynamic resilience abilities, along with organizational dynamic competitiveness positively impact the adoption of GSCM system in the semiconductor industry. This implies that the managers should support the employees to be more agile and adaptable with the changing business environment so that the organizations become more resilient, and the innovative ability of the organization is enriched. For this the managers should arrange periodical knowledge sharing sessions for the employees. Besides, the present research work has revealed that some of the policy and regulation related external issues concerned with business environment such as government policies, regulations, social community, and availability of customers positively influence adoption of GSCM system in the semiconductor industry. This implies that organizational authorities need to keep themselves updated with the government policies and regulations of the locations where the business units are in operation. This will reduce the inefficiencies and could make the organizations more resilient, and the organizations could also do better in sustainability performance by saving energy and improving their sustainability performance. The people in charge of the semiconductor and electronics industry should make sure that the designers make the technological applications easier to prevent any problems for any employees to use modern technologies for applying GSCM system in the semiconductor and electronics hardware industry.

This study provides firms with a thorough understanding of risks and resilience influencing the adoption of green supply chain practices. The decision framework elucidates cause-and-effect relationships, aiding firms in prioritizing their objective to successfully adoption of GSCM system in the semiconductor industry. Addressing primary cause factors is shown to efficiently impact corresponding effects, thereby reducing overall efforts required for green supply chain adoption in the semiconductor industry.

The study underscores the importance for organizations to adhere to regional environmental regulations and stay abreast of contemporary global environmental trends to reassess their environmental objectives. Simultaneously, companies are encouraged to fulfil their corporate responsibilities by managing the ecological and operational impacts of supply chain activities across various social groups. Building an image as a socially and legally and responsible entity is seen as a possible competitive edge. Firms should consult with internal stakeholders on the environmental strategy before embracing green practices. Increased support from various stakeholders enhances the likelihood of achieving sustainability goals. Therefore, a firm needs to show strong leadership, distribute organizational resources, and encourage organizational innovation to make sure that green supply chain activities match with business growth objectives and corporate environmental policy.

7. Conclusions

The present study has taken a novel attempt to enrich the extant literature by synthesizing the factors which include the risks, resilience, and complexities facilitating and impeding the smooth adaptation of GSCM in the semiconductor industry. This study has highlighted how the semiconductor industry could comply the policies and regulations of the governments while adopting the GSCM. This study has also discussed how the business practices in the semiconductor industry which consumes huge energy and pollutes the environment could use green supply chain practices that could lead to business sustainability and fulfils existing environmental related regulations to achieve sustainability goals. This research work has successfully been able to integrate TOE framework along with DCV to develop a hybrid theoretical framework highlighting how semiconductor industry can ensure better adoption of GSCM to achieve their sustainability goals. The proposed framework acts as a tool and guideline for future researchers who intend to ensure GSCM practices in other types of industries by updating the proposed model commensurate with the context of that study. Thus, the proposed model acts as a baseline for future researchers. This study has successfully been able to identify the factors like risk, resilience, and complexity which affect the adoption of GSCM. This study has also found that improvement of dynamic capabilities of the organizations related to semiconductor industry helps to successfully adopt GSCM. Finally, this study has also demonstrated that government policies and regulations have considerable influence on organizations towards achieving sustainability goals through adoption of GSCM.

8. Limitations and future scopes

Despite of all the attempts made by researcher to maintain the rigour of the study, researcher acknowledges certain limitations inherent in this study. First, it focuses solely on the electronics-semiconductor industry within a specific region. The electronics & semiconductor industry in India is rapidly growing and has mostly pursued environmental sustainability, but future research could expand the scope to other countries to see if the results are different. Secondly, for this research study data was collected only from a few people relating to the electronics hardware and semiconductor industry which does not represent an entire society. The future researchers could collect the data from more people, domain expert in the semiconductor industry, policy makers, and so on which will help to make the results more generic. Thirdly, while the Partial Least Squares Structural Equation Modelling (PLS-SEM) method is known to yield robust research outcomes even with a limited sample size, future studies may benefit from exploring alternative techniques. This diversification of methodologies has the potential to enhance the study and provide additional insights. Fourth, the model explains 77% of the variance. However, some steps are required to improve its prediction accuracy, which this study does not address. This is a limitation of this study. Future researchers are encouraged to incorporate additional factors and consider boundary conditions to assess the potential enhancement of the proposed theoretical model. Fifth, another weakness of this study is the lack of an analysis of a different or alternative model. Examining a competing model would have enabled a contrast of the suggested theoretical model's strength with that of the alternative model. Future researchers are advised to pursue this path for more understanding and comparisons.

CRediT authorship contribution statement

Ranjan Chaudhuri: Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Bindu Singh:** Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Amit Kumar Agrawal:** Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Sheshadri Chatterjee:** Writing – original draft, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Shivam Gupta:** Writing – review & editing, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Sachin Kumar Mangla:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Funding acquisition, Conceptualization.

Data availability

Data will be made available on request.

Appendix A. Summary of questionnaire

Items	Source	Statements	Response [SD][D][N][A][SA]
TTR1	Teece et al. (1997); Srivastava (2007)	Getting trained manpower with knowledge of appropriate technology is a risk in semiconductor manufacturing organizations as the technology changes frequently.	[1][2][3][4][5]
TTR2	Teece (2014a); Wang et al. (2023)	I believe there should be contingency plan available in case of any volatile situation hampering global supply chain flow.	[1][2][3][4][5]
TTR3	Hervani et al. (2005); Feng et al. (2022)	I think hardware infrastructure is important to operate smoothly by the semiconductor manufacturing organization during volatile situations.	[1][2][3][4][5]
TTR4	Teece (2014b); Feng et al. (2022)	Rapid changes in technology is a risk for semiconductor manufacturing organization.	[1][2][3][4][5]
TEC1	Borgman et al. (2013)	Semiconductor industry needs complex global supply chain integration technology.	[1][2][3][4][5]
TEC2	Awa & Ojiabo (2016); Mewes & Broekel (2022)	Adequate investment in technology is essential for semiconductor manufacturing organizations for sustainability.	[1][2][3][4][5]
TEC3	Awa et al. (2017)	Our organization has required technologies for green supply chain management.	[1][2][3][4][5]
TEC4	Singh (1997); Awa & Ojiabo (2016)	For smooth global supply chain integration, semiconductor industry needs complex technology.	[1][2][3][4][5]
TCO1	Singh (1997); Ortega et al. (2007)	Technological competency is essential for global semiconductor manufacturing organizations.	[1][2][3][4][5]
TCO2	Awa et al. (2017); Mukherji & Silberman (2021)	I believe that compatible technology is a core requirement for smooth operations of semiconductor manufacturing organizations.	[1][2][3][4][5]
TCO3	Ortega et al. (2007); Awa & Ojiabo (2016)	I think that our organization has compatible supply chain technology for performing smooth operations.	[1][2][3][4][5]
TCO4	Mukherji & Silberman (2021)	Compatible supply chain technology is essential to remain competitive.	[1][2][3][4][5]
DRC1	Chowdhury & Quaddus (2017)	I believe that it is essential for semiconductor manufacturing organizations to quickly adjust with the changing scenarios.	[1][2][3][4][5]
DRC2	Teece et al. (1997); Khurana et al. (2022)	It is essential that each semiconductor manufacturing unit should acquire sufficient dynamic abilities for greater resilience power.	[1][2][3][4][5]
DRC3	Khan et al. (2019)	I think organizations having better dynamic capability will have superior resiliency.	[1][2][3][4][5]

(continued on next page)

(*continued*)

Items	Source	Statements	Response [SD][D][N][A][SA]
INC1	Teece et al. (1997); Hage (1999); Lai et al. (2022)	Innovation plays an important role in the semiconductor industry.	[1][2][3][4][5]
INC2	Srivastava (2007); Crossan & Apaydin (2010); Lai et al. (2022)	Both exploration and exploitative innovation are important to remain competitive.	[1][2][3][4][5]
INC3	Teece et al. (1997); Hage (1999); Teece (2014b)	I believe that semiconductor manufacturing organizations should adequately invest in improving their innovation capability.	[1][2][3][4][5]
INC4	Hage (1999); Crossan & Apaydin (2010)	I think that leadership team support is important to improve innovation capability.	[1][2][3][4][5]
ODC1	Teece (2014a); Swab & Johnson (2019)	Semiconductor manufacturing organization should invest in change management programs to remain competitive.	[1][2][3][4][5]
ODC2	Hitt et al. (1994); Langlois & Steinmueller (1999); Swab & Johnson (2019)	I believe that semiconductor manufacturing organizations should dynamically orient their supply chain flow in case of any turbulent situation.	[1][2][3][4][5]
ODC3	Browning et al. (1995); Teece et al. (1997);	I think that most of the semiconductor manufacturing organizations can survive if they can remain competitive even in crisis.	[1][2][3][4][5]
ODC4	Langlois & Steinmueller (1999)	I believe that surviving in an environmentally dynamic situation is one of the prerequisites for any semiconductor manufacturing organization.	[1][2][3][4][5]
GOP1	Flamm & Reiss (1993); Khan et al. (2021)	Government should incentivize semiconductor manufacturing organizations.	[1][2][3][4][5]
GOP2	Irwin (1996); Ouyang (2006)	I believe that favorable government policies can help flourish semiconductor ecosystem.	[1][2][3][4][5]
GOP3	Ouyang (2006); Khan et al. (2021)	I think countries which have favorable incentive programs for semiconductor manufacturing organizations could attract more investments.	[1][2][3][4][5]
GOR1	Prosser, 2010; Wang & Chiu (2014)	I believe that government should have comprehensive regulations for the semiconductor industry.	[1][2][3][4][5]
GOR2	Watterson (2006); Kim et al. (2014)	I believe sometime over regulation could hamper global supply chain flow for the semiconductor manufacturing organizations.	[1][2][3][4][5]
GOR3	Wang & Chiu (2014); Kim et al. (2014)	I think that government agencies should formulate regulation after discussing with relevant semiconductor industry body or association.	[1][2][3][4][5]
SOC1	Hwang et al. (2016)	The semiconductor industry has enormous potential for employability.	[1][2][3][4][5]
SOC2	Assimakopoulos et al. (2003); Elia et al. (2020)	I believe that the semiconductor manufacturing organizations could provide social community services in their surroundings.	[1][2][3][4][5]
SOC3	Assimakopoulos et al. (2003); Almeida et al. (2010)	I think green supply chain management of semiconductor ecosystem could improve socio-economic condition of society.	[1][2][3][4][5]
CUA1	Singh et al. (1990); Mousavi et al. (2019)	A large consumer base is necessary for semiconductor industry for survival.	[1][2][3][4][5]
CUA2	Singh et al. (1990); Ratusny et al., 2022	I believe that the greater number of consumers of a semiconductor manufacturing organization, better will be their competitiveness.	[1][2][3][4][5]
CUA3	Mousavi et al. (2019); Ratusny et al., 2022	Availability of a large consumer base could guarantee cost leadership.	[1][2][3][4][5]
GSCS1	Feng et al. (2022)	Green supply chain technology could provide cost advantages in the log term.	[1][2][3][4][5]
GSCS2	Lai et al. (2022); Feng et al. (2022)	I believe that green supply chain technology ensures social commitment by the semiconductor manufacturing organizations.	[1][2][3][4][5]
GSCS3	Wang et al. (2023)	I think green supply chain flow requires complex technological competency.	[1][2][3][4][5]
GSCS4	Browning et al. (1995); Lai et al. (2022)	Green supply chain technology for any semiconductor manufacturing organization requires active leadership support.	[1][2][3][4][5]

Note: SD = Strongly Disagree; D = Disagree; N = Neither disagree nor agree; A = Agree; SA = Strongly Agree.

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