

Autonomous Vehicle Adoption and Supply Chain Social Sustainability: Delphi Study and Expert Interviews

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Abstract

Purpose: Autonomous vehicle (AV) adoption has both positive and negative impacts on supply chain social sustainability (SCSS). This paper explores and evaluates the actions that organisations take to address the social impacts of adopting AVs and develops a model for SCSS in this context.

Design/methodology/approach: This study implemented a Delphi study conducted over three iterative rounds to gather and evaluate the actions that organisations take to address social impacts when adopting AVs in supply chains. The panel consisted of 39 experts from industry and academia. The Delphi findings are validated and extended through 14 follow-up expert interviews.

Findings: Our findings identify eight categories of actions used to address the social impacts of adopting AVs in the supply chain. These are discussed in relation to established SCSS indicator categories and an additional category “reputation” is introduced. The categories are also aligned to the technology adoption process to understand how social sustainability implications can be mitigated as AV adoption matures.

Originality: This study builds on Diffusion of Innovation (DOI) theory to propose a refined Innovation Process model for Socially Sustainable Adoption of AVs. This customised model aligns the new action categories with the established stages of the innovation adoption process, uniquely illustrating how to manage the social sustainability impacts of AV adoption as part of the technology adoption process. Identified social supply chain indicator categories are also aligned with the actions for an alternative perspective.

Practical Implications: Practitioners benefit from prescriptive frameworks which provide actions addressing the social sustainability implications of AV adoption. These can be applied either from a social sustainability indicator or innovation adoption process perspective.

Keywords: Supply chain, social sustainability, autonomous vehicle, Diffusion of Innovation, innovation process, action category

Paper type: Research paper

1. Introduction

Autonomous vehicles (AVs) have served the logistics sector for more than half a century, operating in defined territories such as harbours, warehouses, and manufacturing plants as Automated Guided Vehicles (AGVs) (Flämig, 2016). Following Industry 4.0, more advanced AVs have emerged, such as uncrewed ground vehicles (UGVs), autonomous mobile robots (AMRs), self-driving vehicles, and uncrewed aerial vehicles (UAVs) (Schwab, 2016). These AVs have the potential to improve operational, economic, and environmental efficiency in supply chains, by reducing operational cost and carbon emissions or improving accuracy (Tang and Veelenturf, 2019) and as a consequence are being adopted rapidly. For example, commercial autonomous long-haul freight transportation is under trial and operation on public roads in China and the USA (DHL, 2024). While in the UK, autonomous delivery robots are efficiently conducting delivery tasks within a mile radius of the depot, in a number of cities (McLoughlin, 2024). Now that Beyond Visual Line of Sight drone flight approval has been granted to numerous companies by the Federal Aviation Administration, drones are being used to deliver medical and other critical supplies to rural areas, although their application in urban regions remains limited (DHL, 2024). Expanding the scope of UAVs, long-range heavy-load drones are under development, with a heavy-loaded UAV (carrying 4.1 tonnes) having been tested in 2023 (Natilus, 2023).

Whilst development of these new technologies and their adoption is increasing, most currently realised applications remain small either in terms payload or scale and scope. Social and societal concerns related to the autonomous nature of these technologies form the majority of the barriers to wider adoption. Incidents which threaten public safety due to the reliability or immaturity of AV technology such as collisions, fatal accidents, loss of signal, and inability to cope with extreme weather remain a major concern (Perussi et al., 2019, Fagnant and Kockelman, 2015; Marsden et al., 2018). In addition, delivery drones used to conduct terrorist attacks and operate in commercial airline space further threaten public safety (Aydin, 2019; Rao et al., 2016). Cyber security concerns, with cyberattacks on AV systems leading to the leaking of customers' personal information in addition to delivery of parcels to the wrong address, lead to additional privacy concerns (Nelson et al., 2019; Mohamed et al., 2020). Further, AVs threaten to take the jobs of logistics sector employees. Long-haul freight truck drivers, as well as last mile delivery drivers all risk losing their jobs due to services conducted by autonomous vehicles (Sohrabi et al., 2020,). In addition, roles that have traditionally supported conventional vehicles, such as maintenance, finance and diesel supply, face short-term employment disruption (Nikitas et al., 2021). Although job transformation will follow (Klumpp, 2018), it is inevitable that a large number of low-skilled workers will face unemployment, at least in the short-term further threatening social inequality (Ding, 2018). These concerns require any implementation of AVs to be subject to significant regulation and larger scale implementations are limited by current limited regulatory approval. Understanding and mitigating the impacts of these concerns is fundamental to the wider approval and adoption of AVs in the supply chain, however

research in this area remains limited (Kim et al., 2022; Kurniawan et al., 2021; Monios and Bergqvist, 2020). An investigation of the social sustainability implications of AV adoption in supply chains is therefore timely.

Extant literature has identified both positive and negative social impacts of AV adoption in supply chains. Therefore, key stakeholders need to be aware of the actions, initiatives, or solutions (Ghadge et al., 2021) that organisations are carrying out to address these social impacts (Kurniawan et al., 2021). Understanding what actions organisations can implement to overcome the negative social impacts of AV adoption, will help to promote wider societal and regulatory approval and acceptance to alleviate restrictions on AV applications leading to wider adoption overall. This paper illustrates how these actions connect to SCSS and AV adoption, addressing negative SCSS implications and reinforcing positive effects. Finally, leading to an enhanced understanding of the social sustainability implications of AV adoption in supply chains.

In order to understand how organisations address SCSS implications at various stages of AV adoption, this study utilises Diffusion of Innovation theory (DOI) (Rogers, 2003). This theoretical framework is commonly used to understand decision-making when adopting advanced technologies in the supply chain (Wamba and Queiroz, 2020). AVs can be classified as technological innovations as defined by the five attributes of DOI theory (relative advantage, trialability, observability, compatibility, and complexity) (Rogers, 2003; Yuen et al., 2020). DOI provides a theoretical basis for understanding the organisational-level adoption process of technologies in supply chains (Wamba and Queiroz, 2020), through a five-stage Innovation Process (IP): agenda-setting, matching, restructuring/redefining, clarifying, and routinising. This five-stage process model provides a sequential structure to support the changes and activities taking place during AV adoption. This study explicitly incorporates the identified SCSS actions into the organisational IP model to provide a mechanism which allows organisations at various stages of AV adoption to explicitly incorporate SCSS considerations whilst adopting AVs in the supply chain. Thus, proposing an Innovation Process model for Socially Sustainable Adoption of AVs.

Based on this background, the following research questions (RQ) are put forward:

RQ1: What actions address social implications of AV adoption in the supply chain?

RQ2: How can the actions be structured to support decision-making processes for social sustainability in the supply chain when adopting AVs?

There is a lack of research that comprehensively discusses the social sustainability of AV adoption in supply chains. This study, therefore, explores the social implications of both UGVs and UAVs in supply chains, to understand the SCSS implications of AV adoption. This research is informed by a systematic literature review (SLR) that collects and synthesises information without biases in order to create a conceptual background (Tranfield et al., 2003; Durach et al., 2017). As this research is exploratory in nature, a qualitative data collection method is followed (Edmondson and McManus, 2007), specifically the Delphi method is applied as it provides suitable support for the

development of models and frameworks (Okoli and Pawlowski, 2004; Reefke and Sundaram, 2018). A three-round Delphi study establishes the actions and action categories and an AV innovation process model for social sustainability is developed. Follow-up expert interviews evaluate the actions and model against the social sustainability indicators and the DOI framework.

The remainder of this paper is organised as follows. Section 2 reviews the literature as well as underpinning theory and section 3 presents the methodology of the study. Section 4 showcases the findings alongside discussions, whilst section 5 outlines the contributions, limitations, and future research directions.

2. Literature Review

This literature review section was informed through an SLR in alignment with the research questions. It identifies the SCSS implications of AV adoption and actions which organisations and supply chains can implement in response. Further, the actions derived from literature are organised within categories and the use of DOI theory for guiding AV adoption from a social sustainability orientation is put forward as a useful decision support structure. These foundational insights ensured that the empirical investigations are built upon established knowledge and theory. The details of the SLR are not the focus of this study but a rigorous process was ensured through guidelines by Tranfield et al. (2003) and Durach et al. (2017). A pool of peer reviewed papers on the topic were identified through a targeted keyword search in three academic databases followed by a screening process and quality assessment. As reflected in the remainder of this review section, the thematic analysis resulted in the identification of social impacts and indicators, actions and corresponding categories, as well as theoretical perspectives utilised in the context of AV adoption and social sustainability.

2.1 Autonomous vehicles

This study considers both UAVs and UGVs as AVs (Rai et al., 2022). For UGVs, a well-accepted standard of automated driving level published by the Society of Automotive Engineers (SAE) categorised AVs into three levels: Level 3 (conditional automation), Level 4 (high automation) and Level 5 (full automation) (Klumpp and Zijm, 2019; Wang and Li, 2019). Any ground vehicle categorised at level 3 or higher is recognised as an AV (Rai et al., 2022). Typical UGVs in the logistics sectors include automated guided vehicles (AGVs), autonomous mobile robots (AMRs), and heavy-load uncrewed trucks (Flämig, 2016; DHL, 2024). Civil-use UAVs, are mostly small, electrically powered aircraft with limited payload, flight duration and range, including fixed and rotary wing drones and multi-copters (Wang et al., 2021). Their travelling speed and use of low-altitude airspaces make them suitable for parcel and emergency medical goods delivery (Perussi et al., 2019; Tang and Veelenturf, 2019; Scott and Scott, 2017). UAVs are expected to be increasingly adopted in humanitarian logistics due to their fast response in time-critical situations (DHL, 2024).

2.2 Social sustainability indicators

Supply chain sustainability is the integration of economic, environmental, and social considerations with key inter-organisational business systems to effectively and efficiently manage operations, in order to meet stakeholder requirements and improve profitability, competitiveness, and resilience over the short- and long term (Carter and Rogers, 2008; Seuring and Müller, 2008; Ahi and Searcy, 2015; Yawar and Seuring, 2017). Whilst there is no single definition of social sustainability, it is generally considered to concern the human side of sustainability (Huq et al., 2014). This includes aspects such as equity, philanthropy, health and safety, human rights, welfare, labour, and product responsibility (Mani et al., 2018), which qualitatively present SCSS performance (Ahi and Searcy, 2015). A single set of measures for social sustainability does not suit all supply chain contexts (Ahi and Searcy, 2015; Denu et al., 2023), therefore context specific indicators are required.

Extant literature identifies six SCSS indicator categories applicable to AV adoption: Health and safety, customer satisfaction, labour issues, transparency, diversity and equality, and welfare. These indicators can be connected to positive and negative social impacts of AV adoption. Figure 1 presents a categorisation of these AV specific social impacts with the six SCSS indicators.

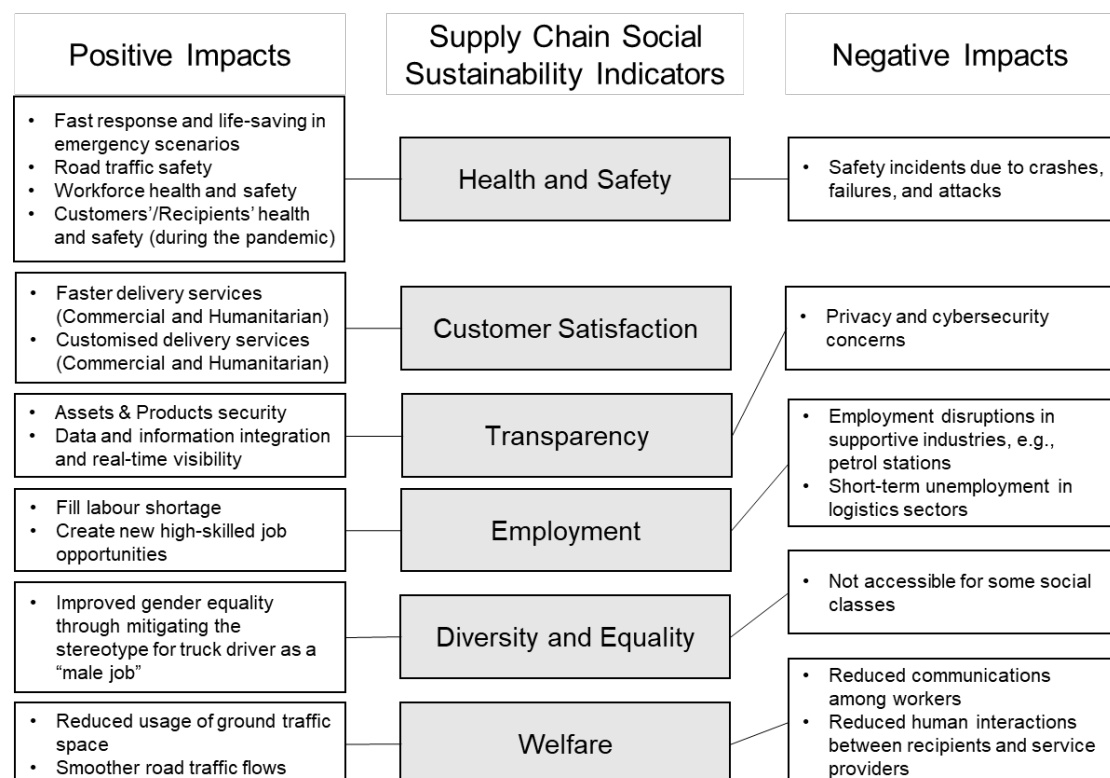


Figure 1 Social impacts and SCSS indicator categorisation (Authors' own elaboration)

Health and Safety

Safety is a major social impact of AV adoption. On the positive side, AVs provide touchless customer delivery services, preventing the spread of contagious viruses,

which is especially relevant in a pandemic (Pani et al., 2020). In workplaces, deploying AVs helps to enhance workforce health and safety by replacing key tasks in hazardous working environments (Bechtsis et al., 2017) and reducing workplace accidents (Llopis-Albert, 2019). The introduction of AVs in freight transport reduces human-error-related traffic accidents, benefiting road traffic safety (Gružauskas et al., 2018).

However, negative impacts such as technology-related safety accidents (Mohamed et al., 2020), terrorist attacks (Aydin, 2019), and invading commercial airline spaces (Rao et al., 2016) should not be ignored.

Customer Satisfaction

The rise of e-commerce and urbanisation has increased the importance of urban logistics, and customer-oriented last-mile delivery services (Kapser et al., 2021). Reduced delivery time and more customised services are demanded by consumers, and these are challenging for conventional delivery modes to achieve (Bechtsis et al., 2017). AVs offer a feasible solution aligned with customers' needs (Merlino and Sproge, 2017). For example, UAVs which are not impacted by ground traffic congestion and impaired road conditions, can satisfy demands for shorter delivery and customer lead times (Perussi et al., 2019; Tang and Veelenturf, 2019; Kellermann et al., 2020; Mohamed et al., 2020). Such characteristics facilitate time-sensitive emergency delivery of medical services in humanitarian and healthcare supply chains (Ding, 2018).

Transparency

Transparency calls for collaboration with stakeholders for information sharing and monitoring to improve supply chain visibility (Carter and Rogers, 2008). In this context, AVs help to realise real-time visibility of asset and product flows in supply chains, which is especially challenging in remote and infrastructure-poor locations (Sellevold et al., 2020). Equipped with smart sensors, drones can carry out asset and inventory surveillance guaranteeing the real-time safety of products, for example in warehouses and pipeline infrastructure (Perussi et al., 2019; Tang and Veelenturf, 2019). This facilitates monitoring of product flows and timely adjustment of operations (Mahroof et al., 2021; Roy et al., 2024). Equipped with built-in sensors, AVs automatically provide real-time visibility, enabling traceability of products during transport without human interference (Gružauskas et al., 2018; D'Amico et al., 2021; Roy et al., 2024).

AVs are vulnerable to hackers resulting in cyber security issues (Nikitas et al., 2021), including the risk of leaking stakeholders' personal information and privacy (Aydin, 2019; Nelson et al., 2019).

Employment

AVs hold the potential to reduce labour shortages in the logistics sector, caused by the combination of an aging and retiring labour force and low birth rates in Generations Y and Z (Hwang et al., 2021, Klumpp and Zijm, 2019). AV adoption can reduce the need to carry out manual and repetitive tasks (Bechtsis et al., 2017, Klumpp, 2018), improving accuracy and efficiency (Tang and Veelenturf, 2019). AV adoption will

require professionals with a new set of technology-related skills, who will be increasingly in demand in the logistics industry of the future (Sohrabi et al., 2020).

AVs will replace operational employees in industries which support conventional supply chains, such as vehicle maintenance, finance, and petrol stations (Nikitas et al., 2021; Marsden et al., 2018). Although job transformation will exist (Klumpp, 2018), ageing and less educated employees with limited transferable skills are more likely to be made redundant before they are ready to retire (Nikitas et al., 2021).

Diversity and Equality

There is a gender imbalance in the logistics sector, with males dominating driving roles (Kim et al., 2022). The adoption of AVs may diminish this imbalance by creating more gender-neutral job opportunities, mitigating stereotypes in logistics and benefiting gender diversity.

Deploying AVs potentially aggravates social inequality by enlarging the gap between social classes (Tang and Veelenturf, 2019). Those who receive less education regarding AV technology and usage will be less willing to accept them (Kapser et al., 2021).

Welfare

Welfare considers human well-being, happiness, and quality of life (Ahi and Searcy, 2015). This study specifically considers traffic congestion, human interactions, and humanitarian applications. UAVs are not impacted by congestion as they use low-altitude air space instead of ground areas and are not subject to geographic infrastructure limitations (Mangiaracina et al., 2019), allowing them to utilise the fastest or most direct route for delivery (Mohamed et al., 2020). UGVs are equipped with smart technologies such as sensors and cloud computing, helping them to optimise their location with respect to other vehicles and smooth traffic flows (Sohrabi et al., 2020). These combined traits in humanitarian setting allow medical deliveries to be made directly to recipients in need (Tatham et al., 2017; Poljak and Šterbenc, 2020; Rosser et al., 2018).

As AVs handle more transportation tasks in logistics, the risk of isolating workers in stationary workplaces and reducing their interactions with colleagues increases (D'Amico et al., 2021). Also, AV delivery services potentially weaken the relationship between healthcare providers and receivers (Tatham et al., 2017). AVs therefore potentially reduce meaningful and necessary interactions among stakeholders in various supply chain scenarios, undermining human welfare.

2.3 Social sustainability action categories

Wider AV adoption needs broad social approval (Kurniawan et al., 2021), which requires the social impacts of AV adoption to be addressed (Kim et al., 2022). To address these social implications of AV adoption, organisations carry out a variety of actions. These managerial actions can be synthesised within four categories: Field

experiments and tests; regulation improvement; education, promotion, and training; and chain-wide view and review. These action categories suggest how organisations address the SCSS concerns of AV adoption and form a stepwise logic, aligned to the level of maturity of AV adoption in an organisation. Detailed references are provided in support of the action categories as shown in Table 1.

Table 1 Action categories from literature (Authors' own elaboration)

Categories	Actions	References
Real-world experiments and tests	<ul style="list-style-type: none"> Preventative measures for drone designs Thorough living lab experiments and tests in small-scale places preliminary. Test the integration of AV operating spaces with other users 	Kellermann et al., 2020; Marsden et al., 2018; Monios and Bergqvist, 2020; Poljak and Šterbenc, 2020; Rosser et al., 2018; Sohrabi et al., 2020; Tatham et al., 2017; Tatsidou et al., 2019.
Regulation improvement	<ul style="list-style-type: none"> Measures for safety, accountability, and privacy No fly zones Data collection and operations protocols Transnational legislative approval Regulations and legal guides, frameworks Subsidising the delivery solutions Mitigate the implications of unemployment Federal guidance for adoption and certifications 	Aydin, 2019; Comtet and Johannessen, 2022; D'Amico et al., 2021; Fagnant and Kockelman, 2015; Haula and Agbozo, 2020; Hwang et al., 2021; Kapser et al., 2021; Kellermann et al., 2020; Kurniawan et al., 2021; Mohamed et al., 2020; Nelson et al., 2019; Rao et al., 2016; Rejeb et al., 2023; Rosser et al., 2018; Sen et al., 2020; Sohrabi et al., 2020; Tatsidou et al., 2019; Wang et al., 2021.
Education, promotion, and training	<ul style="list-style-type: none"> Promote public benefits and risk mitigation methods Introduce AVs to the communities regarding their benefits to health and safety A trained and experienced workforce is needed Education and training for employees through organisational programmes Re-skill strategies for less-educated and lower-skilled employees 	Aydin, 2019; Eißfeldt et al., 2020; Haula and Agbozo, 2020; Klumpp, 2018; Llopis-Albert et al., 2019; Nelson et al., 2019; Nikitas et al., 2021; Poljak and Šterbenc, 2020; Sohrabi et al., 2020.
Chain-wide (re)view	<ul style="list-style-type: none"> Collective stakeholder engagement and participation in resistance mitigation Build relationships with supply chain communities Integrate AVs into smart cities and collaborate with other technologies Assess feedback and behaviours after technologies are available and implemented in practice 	Ding, 2018; Haula and Agbozo, 2020; Kurniawan et al., 2021; Llopis-Albert et al., 2019; Mohamed et al., 2020; Perussi et al., 2019; Sen et al., 2020; Vlachos et al., 2023.

Real-world Experiments and Tests

Conducting pilot testing and real-world experiments forms a fundamental step in the adoption of any technology (Nikitas et al., 2021, Sohrabi et al., 2020). Tatham et al. (2017) and Monios and Bergqvist (2020) argue for pilot tests conducted in a controlled, small-scale setting. Further, new preventative measures should be included in AV designs (Kellermann et al., 2020). In addition to testing of the technology itself, integration of AVs with existing systems should also be assessed (Poljak and Šterbenc, 2020). Rosser et al. (2018) highlight the need to integrate AV operating space with that of other users.

Regulation Improvement

To enable wider AV adoption, regulations need to be adjusted to address limitations and provide updated guidance (Fagnant and Kockelman, 2015; Mohamed et al., 2020; Tatsidou et al., 2019). Regulative changes require proof of concept and real-world

experiments to ensure safe usage and demonstrate the advantages of AVs in practice (Tatham et al., 2017; Marsden et al., 2018). This requires the development of regulatory frameworks, legal considerations (Rejeb et al., 2023; Wang et al., 2021), and guidance for health and safety issues (Sohrabi et al., 2020, Haula and Agbozo, 2020). This is emphasised for humanitarian and healthcare purposes since restrictions may hinder efficient distribution of humanitarian medical supplies (Tatsidou et al., 2019). To improve transparency cybersecurity and data collection protocols are required (Kellermann et al., 2020). Further, it is suggested that improving regulations will mitigate unemployment (Sen et al., 2020) and offer the potential for financial subsidies for AV adopters (Kapser et al., 2021).

Education, Promotion, and Training

Once the concept is proven and regulation in place, awareness and knowledge of AV technologies and their application in supply chains is required. Promotion serves an important role in enhancing awareness, familiarity, and acceptance among end customers and local communities and allows them to determine whether to use the technology (Aydin, 2019; Nelson et al., 2019; Eißfeldt et al., 2020; Pani et al., 2020;). From a managerial perspective it is important to promote the advantages (Sohrabi et al., 2020) and risk mitigation mechanisms (Nelson et al., 2019; Aydin, 2019). Education and training sessions can be provided to employees to upskill them for the new tasks and job roles required after deploying AVs (Klumpp, 2018), and to secure current jobs (Nikitas et al., 2021).

Chain-wide (Re)view

Chain-wide (re)view focuses on stakeholder engagement, planning, and improvement. Socially sustainable supply chains require ethical operations across the supply chain (Sen et al., 2020). Thus, stakeholder engagement is required to mitigate any resistance towards technology adoption (Vlachos et al., 2023; Haula and Agbozo, 2020). Both internal and external stakeholders are involved in the planning and constant improvement processes (Kurniawan et al., 2021; Tatham et al., 2017). Planning actions are essential, such as integrating UAVs into smart city systems, as well as collaborating with technologies (Mohamed et al., 2020) and allocating AVs into supply chain processes (Perussi et al., 2019). These findings highlight the importance of stakeholder involvement and communication (Ding, 2018).

2.4 Linking AV adoption with theory

The nature of AVs and their interaction with stakeholders inside and outside an organisation means that SCSS considerations are fundamental to their adoption in a way that may not be as relevant for other technologies. Our literature review has allowed us to group the actions that organisations take to address the SCSS implications of AV adoption into a set of categories. These categories form a stepwise framework which naturally aligns to the level of maturity and hence the level of adoption of the innovation. This suggests that the actions taken are dependent of adoption stage

and that companies will need to change their approach to ensuring SCSS depending on the maturity of innovation adoption. Theoretical frameworks which govern how innovation can be managed are well known in the literature. Adapting one of these frameworks allows us to synthesise a theoretically underpinned overview of how organisations manage SCSS at different stages of the innovation adoption process.

DOI theory offers a means to enable this and is defined as the process by which an innovation is communicated through certain channels, over time, among the members (individuals or organisations) of a social system (Rogers, 2003). DOI theory is widely deployed to study innovation adoption (Pervan et al., 2005). In supply chain management, DOI has been used in contexts such as block-chain implementation in humanitarian actions (Wamba and Queiroz, 2022) and the diffusion of green supply chain practices within companies (Zhu et al., 2012). It thus applies in the context of disruptive innovation adoptions and allows the related challenges and barriers to be addressed (Gong et al. 2022).

This study investigates the adoption of AVs at the supply chain level. Theories such as the Technology Acceptance Model (TAM) and Unified Theory of Acceptance and Use of Technology (UTAUT) focus on individual-level perceptions of technology adoption (Kapser et al., 2021; Aydin, 2019). Hence, these theories are not as appropriate here. In addition, this study goes beyond investigating the specific factors which affect the adoption of an innovation to understand how the innovation is adopted. Therefore, theories which focus purely on determining these factors, such as the Technology-Organisation-Environment (TOE) framework (Tornatzky et al., 1990) would not allow the nuanced investigation of the complexities of social sustainability in AV adoption, particularly in how the actions and interactions change as adoption progresses which DOI which recognises the stepped process which innovation adoption follows, offers.

DOI defines five characteristics of innovations (Hameed et al., 2012): relative advantage, compatibility, complexity, trialability, and observability of the innovation. UGVs and UAVs can be classified as technological innovations (Schwab, 2016) which align with all of these characteristics (Yuen et al., 2020). AVs have relative advantages in safety and environmental protection compared to conventional vehicles; AVs are compatible with existing traffic systems; they are perceived to be complex; must be tested before adoption; and the benefits of AV adoption can be observed in practice.

Innovation adoption has long been recognised as a stepped process. DOI theory (Rogers, 2003) explains the diffusion process of innovations in a social system and provides a theoretical framework to understand the organisational-level adoption process of technology in supply chains (Wamba and Queiroz, 2020). Evolving out of DOI to effectively assess technological innovation adoption mechanisms in organisations, Rogers (2003) developed a five-stage organisational IP model which is split into initiation and implementation phases. Gong et al. (2022) adopt the five-stage IP to analyse the adoption of blockchain technology in supply chain finance, stating that it offers a practical application logic which can lead to wider adoption in managerial decision support. Heaslip et al. (2018) extend the use of DOI from the organisational

level to the supply chain level in their investigations into supply chain innovation management models in humanitarian logistics. The organisational IP model indicates that, during the process of technology diffusion, the actions that organisations take evolve and the activities and processes required change to reflect an organisations technology adoption maturity (Rogers, 2003). Extending the application to the new dimension of sustainable supply chain management to ensure that innovation is adopted in a socially sustainable way, essential for an innovation such as AV adoption, with their inherent social implications. The actions organisations take to improve SCSS also evolve with innovation adoption stage. This aligns with the categorisation of action categories we have already observed in the literature. We therefore propose a novel adapted organisational IP model for socially sustainable innovation adoption (Figure 2). This extends the original IP model of Rogers (2003) to incorporate how social sustainability challenges evolve with innovation adoption stage and provides a guiding framework for structuring the action categories to align with the different stages of innovation adoption (Rogers, 2003). Reflecting that organisations at various AV adoption stages act differently to address their social sustainability implications. Figure 2 provides a tentative theoretically derived framework, which extends the original framework of Rogers (2003) to postulate how socially sustainable AV adoption might be achieved and will be tested using a Delphi Study and follow up interviews.

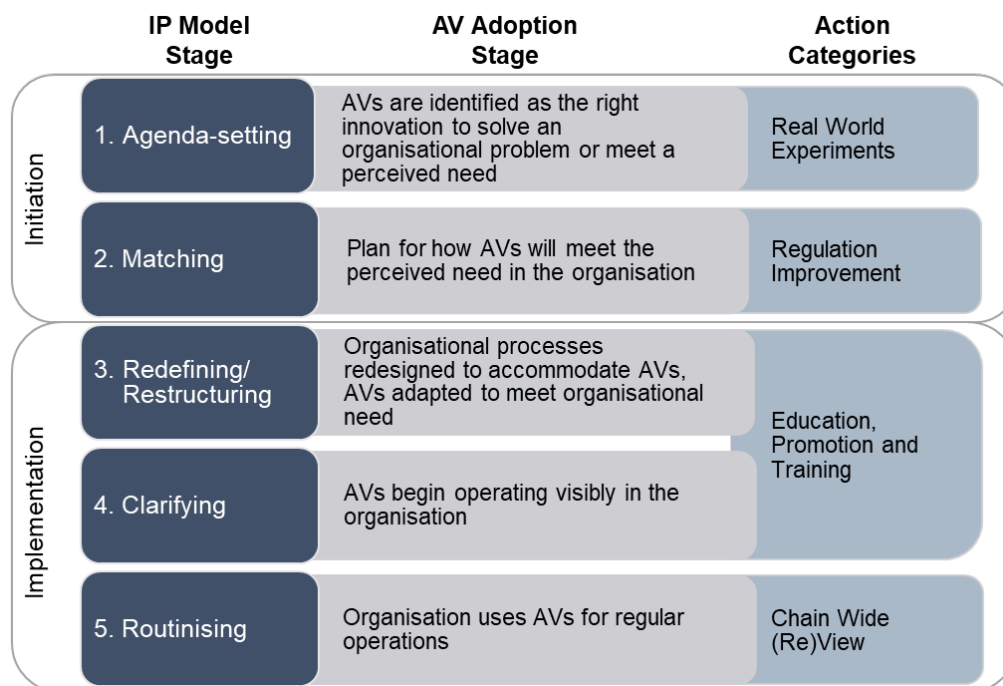


Figure 2 Initial Organisational IP model for Socially Sustainable Innovation Adoption of AVs (Adapted from Rogers, 2003)

3. Methodology

A three-round Delphi study is carried out to identify and evaluate the actions that organisations can employ to address social sustainability impacts when adopting AVs.

In addition, 14 expert interviews allow further evaluation of the actions and validation of the research findings and developments. Insights from the complete study illustrate how the social implications of AV adoption may be addressed. Figure 3 outlines the research steps and timeline for the data collection.

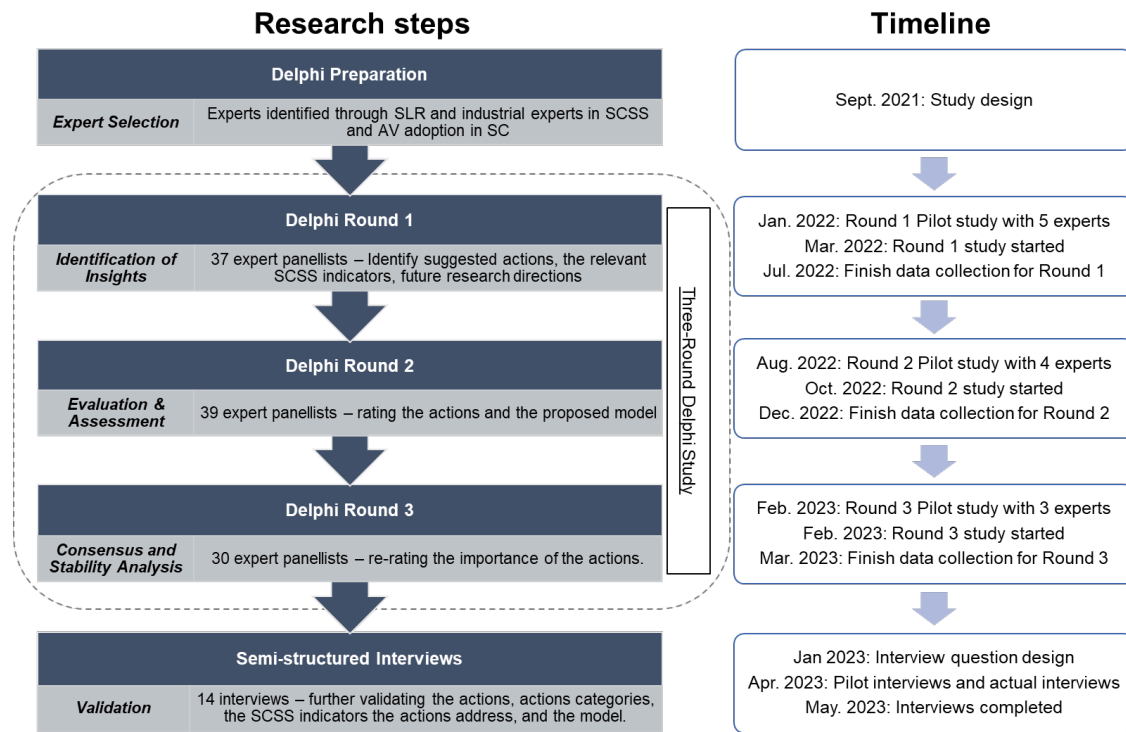


Figure 3 Research process and timeline (Authors' own elaboration)

3.1 Delphi study

The Delphi method is ideal for exploratory research and theory building by gaining consensus from a diverse group of experts sharing a specific interest (Moradlou et al., 2021; Hohn and Durach, 2021; Seuring and Müller, 2008). The combined knowledge of professional and academic experts offers rich information (Reefke and Sundaram, 2017), allowing study of complex topics (De Lima and Seuring, 2023) and construction of targeted models or frameworks in novel contexts (Okoli and Pawlowski, 2004; Reefke and Sundaram, 2018), such as AV application. Other methods, such as focus groups and case studies, were considered, but the Delphi method stands out for gathering expert input on the social implications of AV applications, allowing consensus regarding impacts and models to be established in a systematic manner. This Delphi study avoided the influence of dominating individuals whilst supporting the collection of diverse opinions from a wide range of experts. Further, this study aimed for the quantification of qualitative insights which was supported by the iterative and structured nature of consecutive Delphi rounds.

Thus, this study utilises a three round Delphi based on combined experts' insights on social sustainability implications of AV adoption in supply chains. Delphi studies rely on several considerations, including the selection of appropriate experts and

appropriate strategies for insight identification and assessment.

3.1.1 Expert selection

Selecting an appropriate number of participants with suitable expertise and background is crucial to developing a successful Delphi (Hohn and Durach, 2021). Panel sizes between 20 and 40 participants in the first round is reasonable to cover for potential attrition effects (Reefke and Sundaram, 2017, 2018; Kache and Seuring, 2017). Following established guidance (Reefke and Sundaram, 2017; Moradlou et al., 2021), the participants in this study are either: 1) Academics with a track record in a relevant discipline (e.g., peer-reviewed journal publications); or 2) Practitioners with relevant experience that: a) have at least three years of experience as an SCM practitioner/stakeholder or; b) work as consultants who specifically analyse supply chain trends or technology deployment and have published industrial reports or; c) are employed in sustainability-related roles.

3.1.2 Consensus and stability termination criteria

This study operationalised a combination of consensus and stability analysis, resulting in findings that are both reflective of the combined expert opinions as well as reliable and stable across rounds. The analysis took into account differences in expert participation across rounds and ultimately established that the ratings towards items and models converged towards stable results before the Delphi was terminated.

Delphi studies aim to obtain group agreement on rated items (Seuring and Müller, 2008) with various potential consensus measures (von der Gracht, 2012). Delphi studies that evaluate importance via five-point rating scales can determine consensus by assessing if answers to an individual question receive at least 51% agreement in one category of the scale, or at least 80% agreement in two adjacent categories (Reefke and Sundaram, 2017). Items that have not yet reached a consensus but show convergence in opinions (i.e., a decrease in standard deviation values between rounds), may be moving towards a consensus (Moradlou et al., 2021).

In addition to consensus, stability is another termination criterion used in Delphi studies (von der Gracht, 2012). Stability relates to the response consistency between successive rounds of a Delphi study (Dajani et al., 1979) within a group or among individuals. The outcomes of a Delphi study present the opinions of the group instead of the individual, and hence group stability should be tested for study termination (von der Gracht, 2012; Scheibe et al., 1975).

3.1.3 Delphi process and analysis

Delphi studies depend on capturing sufficient meaningful content through efficient utilisation of the researcher's and participants' time and resources (Mitchell, 1991). If there are no significant additions of items to be evaluated after the second round, a three-round Delphi study is often suitable for reaching a sufficient convergence of opinion (Reefke and Sundaram, 2018; Seuring and Müller, 2008).

Each round underwent pilot testing with experts in Delphi methodology, supply chain sustainability, and technology adoption to ensure the usability and rigour of the questionnaires and support the reliability of results.

Round 1

The first round focussed on gaining insights from each participant regarding the key actions necessary to address the social impacts of AV adoption in supply chains. The questions posed to the panel are listed below:

- What are the actions/measures/processes recommended or applied to mitigate/reduce/prevent negative social impacts?
- What are the actions/measures/processes recommended or applied to maintain/ensure/improve positive social impacts?
- Any additional comments on your understanding or experience.

The obtained insights were coded and grouped by similar meaning. Codes were synthesised and consisted of subthemes (actions), with similar aspects combined into common themes (Saunders et al., 2019). The refined codes and themes (action categories) formed the basis for the second round.

Rounds 2 and 3

The second round rated the actions addressing positive and negative implications within eight action categories in terms of importance. A five-point rating scale (Table 2) was utilised for measuring level of importance, including a 'not applicable' (N/A) option that allowed participants to provide a 'non-answer' (Kache and Seuring, 2017).

Table 2 Five-point Likert rating scale

Numerical value	1	2	3	4	5	-
Importance Scale	Not at all	Slightly	Moderately	Considerably	Extremely	N/A

For any items that had not reached consensus after round two, the participants in round three were presented with the Mean (M) and Standard Deviation value (SD) of the results of the previous round. Only participants who contributed to the second round were invited to the third round. Table 3 provides an overview of the expert participation across the three rounds, showing a high participation of industry and academic experts overall with relatively low attrition. Tables 4 and 5 list the participants' details.

After the second round, four out of 43 questions reached consensus, and by the end of the third round, 35 out of 43 questions met the consensus criteria. All other items showed a convergence of opinions among the experts and/or had reached stability. As no further insights were likely to be gained, the Delphi was closed.

Table 3 Delphi participation across rounds

Panel	Round 1	Round 2	Round 3
Academics	22	22	18
Practitioners	15	17	12
Total	37	39	30

Table 4 Academic Delphi participants

Academics Job Title	Field of Expertise			Years of Experience			Participated in Rounds		
	AVs	SCM	Sustainability	3 - 9	10 - 19	>=20	R1	R2	R3
Reader		√	√			√	√	√	√
Adjunct Professor		√			√		√		
Head of Institute	√	√	√			√	√		
Director of Education	√	√	√			√	√	√	√
Assistant Professor	√	√		√			√	√	
Associate Professor	√	√	√	√			√	√	√
Professor		√	√		√		√	√	√
Professor	√	√	√		√		√	√	√
Professor	√	√	√		√		√	√	√
Professor	√	√	√			√	√		
Professor	√	√	√			√	√		
Associate Professor	√	√				√	√	√	√
Professor	√	√	√			√	√	√	√
Professor	√	√	√			√	√	√	√
Professor	√	√	√	√			√	√	√
Associate Professor	√	√	√	√			√	√	√
Associate Professor	√	√				√	√	√	√
Researcher		√	√			√	√	√	√
Associate Professor	√	√	√	√			√	√	
Researcher	√	√		√			√	√	√
Head of the Group	√	√			√		√		
Professor		√				√	√	√	√
Senior Lecturer	√	√				√		√	
Associate Professor	√	√		√				√	√
Senior Lecturer		√	√			√		√	
Senior Lecturer		√	√			√		√	√
Research Director		√	√			√		√	√
Total							22	22	18

Table 5 Practitioner Delphi participants

Practitioners Job Titles	Field of Expertise			Industry/Background	Years of Experience			Participated in Rounds		
	AVs	SCM	Sustainability		3 - 9	10 - 19	>=20	R1	R2	R3
Consultant	√	√	√	Consultancy			√	√	√	√
Vice President Supply Chain	√	√		Logistics Service Provider		√		√		
Chief Operations Officer		√		Logistics Service Provider			√	√	√	
Global Head Supply Chain Finance	√	√		Consultancy		√		√	√	√
Senior Consultant	√	√		Consultancy	√			√		
Chief Operations Officer	√	√		Technology Provider	√			√	√	√
Business Development Lead	√	√		Technology Provider	√			√	√	√
Project Manager	√	√		Manufacturer			√	√	√	√
Associate Director	√	√	√	Consultancy			√	√	√	√
Transport Manager		√		Logistics Service Provider	√			√	√	√
Consultant	√	√		Investor		√		√	√	
Vice President Innovation Europe	√	√	√	Logistics Service Provider		√		√	√	
Managing Director	√	√		Logistics Service Provider		√		√	√	√
Pre-sale Manager	√	√		Manufacturer				√	√	√
Head of Division	√	√	√	Government			√	√		
Director	√	√		Technology Provider	√				√	√
Supply Chain Executive	√	√		Manufacturer			√		√	
Chief Executive Officer	√	√	√	Consultancy		√			√	√
Senior Manager		√	√	Logistics Service Provider			√		√	√
Vice President Global Innovation	√	√	√	Logistics Service Provider			√		√	
Total								15	17	12

3.1.4 Consensus building assessment

In order to illustrate the consensus building process, an analysis of the average response deviations was conducted (Reefke and Sundaram, 2017; 2018; Moradlou et al., 2021) for the 30 participants who responded to rounds 2 and 3. The plot shown in Figure 4 visualises by how much the individual participants adjusted their combined answers for Round 3 in response to the feedback provided from the previous Round 2. As can be seen from the Delphi experts' responses, all participants utilised the feedback provided for re-evaluation. Academics and practitioners displayed similar consensus building behaviour and significant differences in opinions were not evident between the two groups, supporting termination of the Delphi study after three rounds.

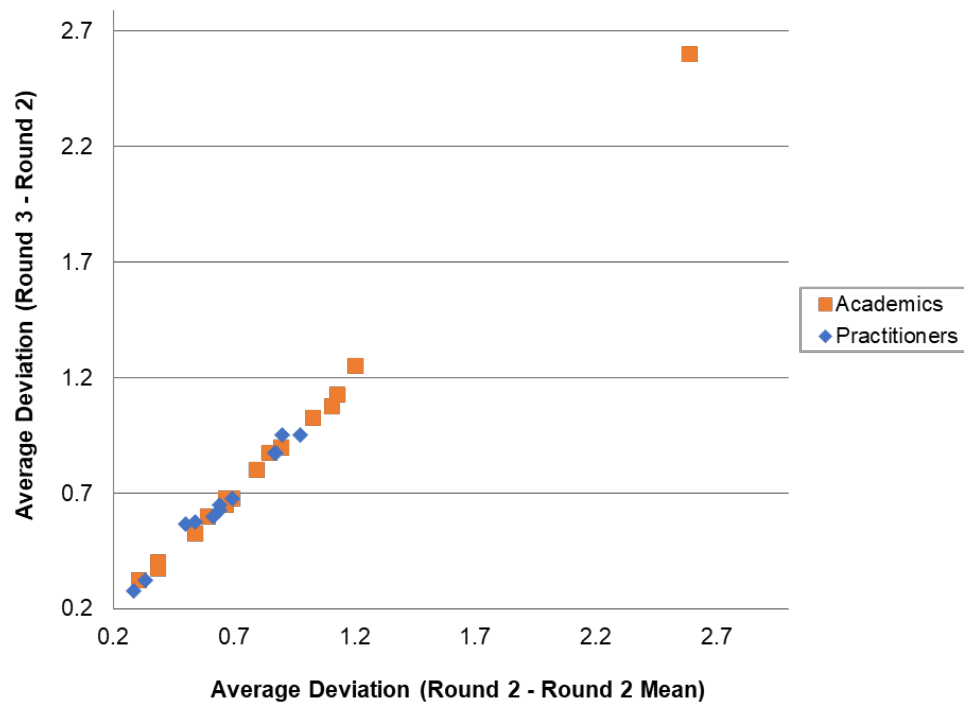


Figure 4 Consensus building process in the Delphi study

3.1.5 Stability assessment

To objectively check group stability, Dajani et al. (1979) propose the Chi-square test which measures if response frequencies in a rating round show significant changes to the previous round. If not, the study can be said to have reached group stability. Following the guidance of Dajani et al. (1979), two hypotheses were raised:

H0: The Delphi rounds are independent of the responses.

H1: The Delphi rounds are dependent on the responses.

If the null hypothesis (H0) cannot be rejected, then the results do not demonstrate significant dependency between the round and response, indicating that the response frequencies do not change significantly between the rounds (Dajani et al., 1979). If the null hypothesis is rejected and hypothesis (H1) holds, this suggests that significant changes in response frequencies between the rounds are evident.

Table 6 presents the Chi-square test results for the 39 questions in Round 3. At a significance level of 0.05, the minimum Chi-square critical value is 5.991 and all of the Chi-square statistics have values less than 0.7, group stability is therefore confirmed.

Table 6 Chi-Square Test Results

Question No.	Chi-Square value	Question No.	Chi-Square value	Question No.	Chi-Square value
1	0.565	14	0.12	27	0.501
2	0.48	15	0.33	28	0.43
3	0.35	16	0.21	29	0.10
4	0.67	17	0.45	30	0.44
5	0.22	18	0.45	31	0.40
6	0.14	19	0.01	32	0.70
7	0.40	20	0.12	33	0.20
8	0.12	21	0.03	34	0.18
9	0.12	22	0.12	35	0.31
10	0.19	23	0.34	36	0.27
11	0.02	24	0.81	37	0.17
12	0.04	25	0.10	38	0.10
13	0.08	26	0.30	39	0.09

3.2 Expert interviews

Follow-up interviews are useful in order to verify, generalise, or extend the results collected from the Delphi study (Hassan et al., 2015). This study aimed to align the identified actions with DOI theory and the IP model. The interviews facilitated this alignment and allowed exploration and confirmation of relationships between actions, stakeholders and social impacts. The Delphi results served as a guide for the interviews, focused primarily on the following:

- Validation of the identified actions and action categories for addressing social impacts associated with the six SCSS indicators.
- Alignment of the action categories with the Innovation Process (IP) model.

3.2.1 Interviewees

The interviewees require a thorough understanding of the research topic and the Delphi results. The Delphi participants had already been identified as experts, the interviews allowed them to reflect on and evaluate the Delphi results to provide deeper insights with higher rigour (Saunders et al., 2019). Interviewees were selected from the pool of Delphi experts and their profiles are outlined in Table 7. Interviewees 10 and 11 (marked “**”) also acted as pilot testers for the interview structure and content.

3.2.2 Interview data analysis

Executing thematic analysis (Saunders et al., 2019), the interview data were coded according to the SCSS indicators, actions, and action categories, maintaining traceability to the individual interviewees (Reefke and Sundaram, 2017). The IP model alignment was achieved by specifically discussing the model design, components and applicability with the interviewees. Several quotes are cited as evidence in the later findings section.

Table 7 Interviewee profiles

Interviewee	Background	Job title	Years of experience
1	Academic	Professor	34
2	Academic	Professor	14
3	Academic	Senior Lecturer	21
4	Academic	Professor	37
5	Academic	Visting lecturer	25
6	Academic	Director of Education	27
7	Academic	Professor	5
8	Academic	Researcher	5
9	Academic	Professor	18
10*	Academic	Associate Professor	22
11*	Academic	Associate Professor	8
12	Practitioner	Managing Director	10
13	Practitioner	Associate Director	20+
14	Practitioner	Chief Executive Officer	10

4. Findings and Discussion

This section presents the findings of the Delphi study and expert interviews which are supported through quotations from the collected data and discussed in connection to literature. Section 4.1 establishes action categories and allocated actions that address social sustainability implications during AV adoption, while section 4.2 illustrates how these actions align with social sustainability indicators. In combination, these findings answer RQ1. RQ2 is addressed in section 4.3 utilising our empirical findings to adapt the literature derived process model for socially sustainable adoption of innovations such as AVs.

4.1 Extended action categories

The Delphi study extended the four literature derived action categories, adding context specific categories and additional actions. Categories one and two “Real-world experiments” and “Regulation improvement” have remained essentially the same. Category three, “Education, Promotion, and Training” is split into two categories, “Human Resource (HR) management” and “Promotion” and a number of new actions not seen in the literature are added to both categories. The results demonstrated that a company’s HR function focuses on internal stakeholders such as employees, whereas Promotion targets external stakeholders such as customers and wider communities. Category four, “Chain-wide (Re)View” is split into four categories. “Communication and Stakeholder Involvement” and “Planning” include actions facilitating the integration of AVs into the local context and organisations. “Continuous Improvement” describes actions which allow AVs to provide better services and Corporate Social Responsibility (CSR) includes actions where AVs enhance CSR at each supply chain node. New actions, not seen in the literature are introduced into all of these categories with Continuous Improvement and CSR being composed entirely of newly identified actions.

Table 8 presents the individual actions grouped into the eight categories, along with their Delphi study importance ratings. This sets out the actions used to address social implications of AV adoption in the supply chain, hence answering RQ1. Any actions specified in literature but not identified in the Delphi are labelled “(L)”.

Communication and Stakeholder Involvement

Participants emphasised the important role of communication and engaging with stakeholders in the supply chain, both from a strategic (setting expectations and journey mapping design) and an operational (team meeting) perspective. These actions mitigate resistance from stakeholders and facilitate the implementation of other actions aimed at improving social sustainability and promoting wider AV adoption (Yang and Basile, 2022).

Therefore, the “communication and stakeholder involvement” category calls for clear communication and active engagement with the internal and external supply chain stakeholders to enhance information sharing and clarify expectations, improve collective group knowledge and awareness to mitigate resistance and avoid miscommunication (Ding, 2018; Vlachos et al., 2023).

Continuous Improvement

Various continuous improvement actions were provided by the participants, including specifying the technology, services, working environment, and working modes within an organisation that suit the adoption of AVs. These aspects specify “what to do for continuous improvement”, and also “how to do” through e.g. AV lifecycle status transparency; feedback loops and behaviour measures.

The continuous improvement category calls for on-going technology development, change management, and improvement in services and working environments in the supply chain. These efforts concern the renewing of organisations’ structure, directions, and capabilities for satisfying stakeholders’ needs (By, 2005).

Corporate Social Responsibility

Current literature does not discuss actions that specifically target how the adoption of AVs impacts CSR performance. The Delphi participants proposed that to address the social sustainability implications of AV adoption, organisations should set strategic CSR performance goals. These goals should then be implemented in daily operations using CSR performance frameworks and metrics and through regular performance checks. AV adoption requires high-level decision-making supported by operational-level monitoring of social sustainability impacts. The CSR actions specifically include reducing stakeholder risks and maintaining ownership of one’s actions.

Human Resource Management

Extending existing literature, the Delphi study identified actions such as new job position creation, cooperation with external training institutions, and employee psychological support, expanding the scope of employment-related practices. The newly introduced actions highlight how employees can be trained and supported when

AVs are adopted in the supply chain and the creation of new job opportunities.

Employment-related actions which form the HR Management category, include people resourcing, employee wellbeing, and employee learning and development (Armstrong and Taylor, 2020). These aspects seek to prepare and qualify employees within the supply chain for AV adoption.

Planning

The Delphi identified actions related to specific planning practices including business environment, data and information integration, Governance, Risk, Compliance (GRC) measures, and route planning. These actions support the integration of AVs into supply chain processes and broader contexts, such smart cities (Mohamed et al., 2020).

Planning involves mapping and analysing how AVs serve the supply chain and stakeholders prior to adoption and implementation. This covers long-term, supply chain-wide mechanisms for the integration of AVs, as well as the short-term, floor-level scheduling of AV operations.

Promotion

The promotion category covers actions relating to the audience, as well as the method of promotion. The purpose of promotion is to demonstrate the benefits of AVs in the supply chain and to mitigate resistance. The audience includes both internal and external stakeholders. This highlights the importance of quantifying the benefits of AVs compared to the conventional vehicles, providing clear evidence strengthening stakeholder confidence in AVs.

Therefore, promotion is about improving awareness and knowledge of AVs among supply chain stakeholders. Since familiarity plays an essential role in determining whether to accept a technology (Aydin, 2019), promoting the benefits of AVs with successful case examples is recommended to enhance stakeholder familiarity and positive perceptions of AVs.

Real-world Experiments and Tests

Extant literature proposes several actions detailing real-world experiments, which were confirmed by the Delphi participants. Highlighting the crucial role of such experiments and tests in demonstrating proof of concept in AV adoption. Therefore, this category involves actions which test the reliability of the technology, alongside safety assurance and risk prevention (Poljak and Šterbenc, 2020; Kellermann et al., 2020).

Regulation Improvement

Actions regarding regulation improvement are widely covered in the existing literature and their importance is further confirmed through this Delphi study. Regulation improvement calls for AV specific refinement of existing regulatory frameworks to address safety, employment, and privacy issues, and to regulate the usage of different types and specifications of AVs. These actions aim to allow the relaxation of extant restrictions to enable broader AV adoption in supply chains (Rao et al., 2016) whilst also enhancing social policies.

Table 8 Extended action categories and importance ratings

Category	Action	R2 M	R2 SD	R3 M	R3 SD
Communications and Stakeholder Involvement (CSI)	Clear communication through the whole supply chain among stakeholders (CSI-1)	4.13	0.69		
	Provide information and set expectations among supply chain processes (CSI-2)	4.05	0.90	4.17	0.70
	Continuous team meetings with different levels of employees (CSI-3)	3.74	0.98	3.93	0.69
	Stakeholder involvement and engagement in developing, planning, and implementation (CSI-4)	3.87	0.91	4.20	0.61
	Stakeholder journey mapping to check social changes (CSI-5)	3.62	0.95	3.83	0.75
Continuous Improvement (CI)	The constant development of AV technologies (CI-1)	4.08	0.92	4.33	0.76
	Development of a working environment for existing employees (CI-2)	3.82	0.81		
	Active change management (CI-3)	4.10	0.81	4.27	0.64
	AV lifecycle status transparency for better service (CI-4)	3.69	0.96	4.10	0.72
	Constant improvement via feedback loops (CI-5)	4.13	0.91	4.27	0.64
Corporate Social Responsibility (CSR)	Regular security and safety checks for reduced stakeholders' risks (CSR-1)	3.90	0.90	4.03	0.67
	Businesses to be responsible for their actions and focus on CSR (CSR-2)	3.87	0.97	4.07	0.74
Human Resource Management (HR)	Internal upskilling and training programmes to requalify the higher-skilled positions (HR-1)	3.82	0.95	4.12	0.64
	Cooperation with external training institutions (HR-2)	3.21	1.04	3.50	0.73
	Create new job positions to prevent the loss of positions due to AV adoption (HR-3)	3.69	0.94	3.80	0.76
	Employee psychological supports (HR-4)	3.44	0.93	3.43	0.82
	Developing reskilling strategies for less-educated and lower-skilled employees (L) (HR-5)				
Planning (PL)	Recruiting more highly trained and experienced workforce (L) (HR-6);				
	Route planning (PL-1)	3.43	1.10	3.65	0.80
	Designing and integrating technologies into supply chain processes (PL-2)	3.94	0.93	4.07	0.58
	Appropriate Governance, Risk and Compliance (GRC) measures, balanced scorecard and data analysis capabilities (PL-3)	3.61	0.93	3.80	0.76
	Appropriate business environment (PL-4)	3.69	0.96	3.90	0.66
	Data and information integration (PL-5)	4.21	0.91		
Promotion (PRM)	Integrating AVs into smart cities and collaborating with other technologies (L) (PL-6)				
	Quantify the benefits compared to the past (PRM-1)	3.90	0.92	4.20	0.66
	Promote and introduce the AVs to the public about the trial samples, the benefits and improvements (PRM-2)	3.66	1.00	4.00	0.66
	Promote to the employees for the system capabilities and interconnectivity (PRM-3)	3.65	1.03	3.85	0.77
Real-world Experiments (RWE)	Promoting to the communities the benefits and risk mitigation methods (L) (PRM-4)				
	Trials of AVs to prove the concepts and benefits (RWE-1)	4.12	0.82	4.52	0.57
	Preventative measures for drone designs (L) (RWE-2)				
	Tests the integration of airspaces (L) (RWE-3)				

Regulation Improvement (RI)	Clear regulations on approving each type of technology in different usage scenarios (RI-1)	4.00	0.99	4.27	0.60
	Financial subsidies for AV operators and the AV adopters (RI-2)	3.11	1.04	3.19	0.90
	Social-wide policies to deal with job loss to automation (RI-3)	3.62	0.89	3.77	0.63
	Transnational legislative approval (L) (RI-4)				
	Regulatory Measures for safety, accountability, and privacy (L) (RI-5)				
	No fly zones (L) (RI-6)				
	Data collection and operations protocol (L) (RI-7)				
	Federal guidance for adoption and certifications (L) (RI-8)				

4.2 Actions addressing SCSS

The Delphi study and follow-up interviews identify 40 actions organised within eight action categories. These actions address the social implications of AV adoption in supply chains, answering RQ1. The research also suggests the additional indicator “Reputation”, extending the range of social sustainability indicators to seven. This section links the identified actions to the SCSS indicators through a cause-and-effect diagram, commonly used to explore the factors that contribute to an outcome (Ishikawa, 1990). Figure 5 illustrates how the actions and action categories align with the social sustainability indicators. The focus here is on visualising the specific elements which contribute to SCSS, enabling decision makers to understand the dynamics involved, and implement decisions aligned with their particular AV adoption requirements.

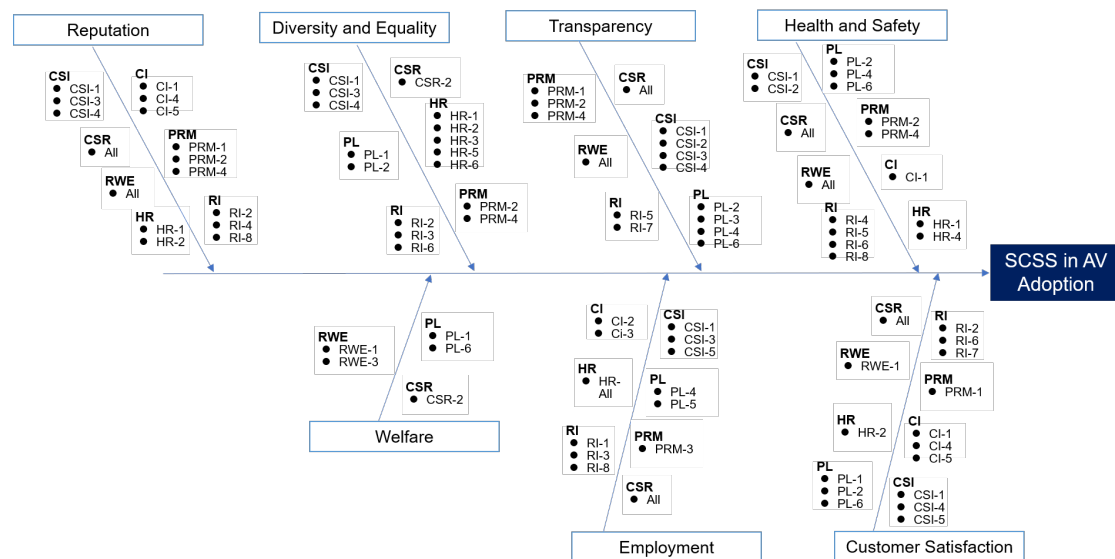


Figure 5 Cause-effect model for the actions addressing SCSS in AV adoption (Authors' own elaboration)

Health and Safety

When drawing up adoption plans, decision-makers should make health and safety a priority. Health and safety actions connect various supply chain stakeholders and include aspects such as upskilling, mental support, and promotion for risk mitigation. One interviewee highlights that regulatory risks must be managed and mitigated before addressing operational benefits:

“The regulators do not care so much if it turns out to not be a good strategy from a business perspective. But they care about if there’s one accident in which an AV kills one person, that is a disaster.” (Interviewee 2)

Customer Satisfaction

Although all of the action categories include customer satisfaction, two actions were especially highlighted: regulated financial subsidies and preventative training sessions.

For financial subsidies, allow organisations adopting AVs to worry less about operational costs and cash flows (Xiang and Worthington, 2017) reducing costs for the final customer. This study indicates financial incentives play a role helping to drive AV adoption.

In addition, disruptions in a single node of the supply chain can lead to a ripple effect or risk propagation that disrupts the whole network, undermining customer satisfaction (Xu, 2020). One academic proposed that appropriate training sessions for preventative maintenance can prevent such disruptions from happening:

“Plan preventative maintenance on it rather than breaking down halfway. If that fails, even if it’s a failure for several minutes, it will have a significant ripple effect throughout that shift.” (Interviewee 6)

Transparency

Transparency is addressed by the actions which involve inter-personal communications such as stakeholder involvement, promotion, and planning. Making sure that information is clear to all stakeholders and establishing trust is fundamental to transparency and to promoting AV adoption. As commented by a practitioner:

“If you don’t have transparency, you generally don’t get trust, you’ll struggle with change management and the implementation of these transformational changes within an organisation.” (Interviewee 12)

Planning is a critical step for mitigating misunderstanding and mistrust in the initial stages of AV adoption (Pani et al., 2020). Transparent planning of how to collect and manage stakeholder data addresses stakeholders’ concerns about privacy issues (Tang and Veelenturf, 2019). It also benefits internal stakeholders by improving data visibility for decision-making (Selleqvold et al., 2020).

Employment

This category is addressed by a wide spectrum of actions. Change management is especially important as it includes a number of aspects such as organisational structure, adoption standards and agenda, safety protocols, and employee working modes and styles (Calderelli et al., 2021). In addition, since unemployment is the major negative social implication in this context, HR management is crucial. This includes understanding how roles will evolve, which employees to recruit, upskill, and lay off, the new skills required and training to develop. As confirmed by a practitioner:

“It’s all about how the skill mix changes. Planning the transition is a need. First is to identify what capabilities you actually need – are the robot maintenance skills different to the capabilities you have already or is it essentially the same.” (Interviewee 13)

Diversity and Equality

When promoting AV delivery services, service providers need to consider customer diversity, including gender, age, educational background, social class, neighbourhood

locations etc. (Yawar and Seuring, 2017). It is important to understand the demands of groups living in remote regions where conventional delivery vehicles are costly to access and AVs potentially have an important role. Increased female involvement is highlighted for employment-related diversity by the creation of new gender-neutral positions in the logistics sectors to mitigate the “male dominant sector” stereotype. In addition, developing targeted promotion strategies for a diverse set of audiences, with varied religion, race, and social class is considered to be worth the effort to be equal. Education which cuts across the social classes is necessary to ensure that everyone has knowledge and awareness of AV technologies. Hence, candidates from all social classes should have opportunities to compete for AV-related positions in supply chains. As highlighted by an interviewee:

“We need to promote this type of technologies and the capability and the interest in coming into these industries to a diverse audience of people to ensure that we get the best chance of innovation. We ensure that it works for them all.” (Interviewee 12)

Welfare

When integrating AVs with smart cities, technology-assisted capabilities for route selection and planning mitigate road traffic congestion (Bezai et al., 2021; Yaqoob et al., 2019). Additionally, real-world experiments address congestion and inter-human/human-machine interactions (Klumpp, 2018). One interviewee connected these considerations with drone testing and airspace integration with conventional civil aircraft. This would apply to resolving air traffic situations and the well-being of human pilots:

“If you extend welfare from road traffic congestion into the air space, human interactions (become important). Here we are talking about potential air-human interaction. So, if I understand correctly, the welfare is getting in, in terms of the interaction of airspaces.” (Interviewee 5)

Welfare connects to human experiences particularly relevant to humanitarian and healthcare logistics. In such settings a higher level of acceptance of AVs is observed, compared to commercial contexts (Eißfeldt et al., 2020). The positive implications of welfare need to be emphasised through actions related to experiments and tests and planning for implementation:

“Probably one of the most important aspects to consider (for sustainable AV adoption), is the welfare of the society in which that AV serves.” (Interviewee 12)

Reputation

Presenting a socially sustainable image when adopting AVs in supply chains was highlighted by some of the interviewees:

“How CSR setup within the organisations’ images will also be crucial – the directors are looking not only for the company to be responsible, but to be seen to be responsible.” (Interviewee 5)

By definition, 'reputation' refers to "the image of an organisation which represents public sentiment in terms of the actions of the organisation" (Carter and Rogers, 2008). Organisations which adopt AVs for operations establish an "innovative" image in their communities, and those organisations which act ethically reinforce their reputation as having socially sustainable AV operations. Hence, it is necessary for organisations not only to act sustainably, but also to showcase their socially sustainable actions, when adopting innovative technologies. That is to integrate a socially responsible organisational culture (Pollach, 2015) with an "innovative" organisational image. Creating a responsible image also affects customer choice, as highlighted:

"I think you are going to see more consumer choice move away from organisations that don't show a strong CSR governance when using AVs." (Interviewee 12)

4.3 Innovation process for AV adoption

The nature of AVs means that SCSS considerations are fundamental to their adoption in a way that is not as relevant for other technologies. Utilising DOI theory and the IP model, we seek to use our empirical results to extend the DOI and IP derived theoretical framework proposed in Figure 2. This refined framework shown in Figure 6 aligns the revised action categories with the adoption stages, thus providing an innovation process model for SCSS improvement customised for AV adoption. This framework sets out which actions organisations at various AV adoption stages should implement for improved SCSS performance, answering RQ2. Our findings demonstrate that not only are the categories of actions more granular and nuanced those originally derived from the literature, but they also do not align to the five IP stages in the straightforward way suggested in Figure 2. This reiterates that SCSS challenges need addressing in different ways at different stages of AV adoption. Some categories are so vital to ensuring SCSS that they are applicable to all stages (e.g. CSR). Others such as Regulation Improvement are confined to the Initiation phase and Continuous Improvement to Implementation, whilst categories such as Human Resources cut across the model. The following discussion describes how the refined action categories are aligned to the stages of the IP model to ensure socially sustainable innovation adoption of AVs.

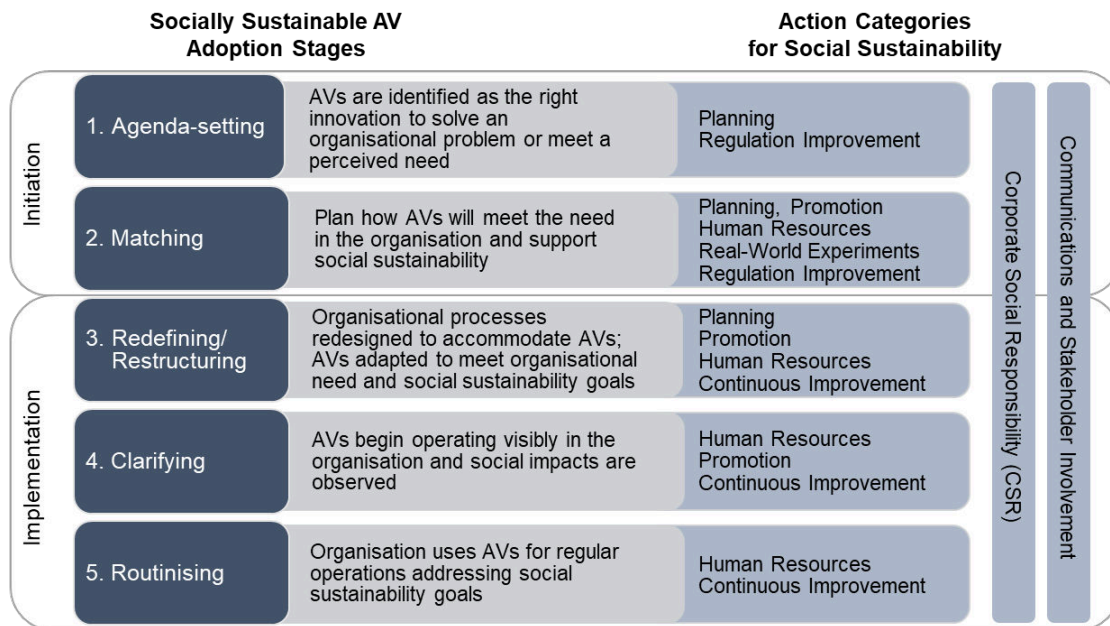


Figure 6 Innovation Process model for Socially Sustainable Adoption of AVs (Authors' own elaboration)

Overarching categories

CSR and communications and stakeholder involvement are important throughout the adoption process. In the early stages, CSR involves strategic level decision-making aligned to sustainability goals, while at later stages, CSR performance should be ensured through refining and checking the measures and indicators at the operational level. Communication and stakeholder involvement acts as an enabler, providing a foundation allowing the other action categories to help the organisation realise improved social sustainability (Yang and Basile, 2022).

Agenda-setting

Organisations at the agenda-setting stage identify how AVs can potentially address the perceived needs or problems, and address a gap between expected and actual performance (Rogers, 2003). Organisations at this stage must work within the initial and often restrictive regulatory environment. Hence, developing a strategic plan for integrating AVs into current operations is essential at this early stage of AV adoption. Organisations ensure that a strategic CSR vision is incorporated throughout the AV adoption process and is integrated into the organisational culture (Slack et al., 2015). Interviewee 5 highlights the need for strategic planning and CSR focus at the agenda-setting stage:

"It goes into how we do things around here within the organisation. I think CSR needs to be earlier in the decision-making process". (Interviewee 5)

Matching

At this stage, organisations seek to design a fit between the AV technology and the identified problems (Rogers, 2003). Hence, the CSR issues of AV adoption must be

identified and a plan designed that mitigates the negative impacts. This establishes the foundation for real-world experiments that aim to test whether the technologies and the AV solutions fit with the organisation in practice. Based on the results, organisations determine whether to move forward to implementation or not (Rogers, 2003). At the matching stage, experimental outcomes serve as proof of concept to promote the case for wider AV adoption to policy-makers (external stakeholders). They provide solid evidence on which to refine the regulations governing implementation of AVs in operations. Therefore, a CSR focus and clear communications, planning, HR management, and promotion related actions are core to the matching stage:

“There is a stop check here. We have to prove that it’s technically feasible with benefits and therefore, we can put pressure on legislation changes.” (Interviewee 1)

“We cannot integrate it into the internal organisation if there is no regulation improvement. How can we use it in organisations?” (Interviewee 11)

Redefining/Restructuring

As the first stage of the actual implementation, alignment is required between the organisation and AV adoption (Rogers, 2003). Continuous improvement actions begin at this stage to constantly refine the technological fit of the AVs to the organisation, working modes and change management processes (Caldarelli et al., 2021; Atilgan and McCullen, 2011). Operational planning such as floor-level planning and scheduling are also required to achieve an appropriate fit. With the technology implementation, effective internal promotion and upskilling programmes are necessary to mitigate resistance from internal stakeholders and ease potential difficulties in later implementation (Rogers, 2003), and to enhance employees’ confidence in interacting with AVs. Actions related to operational planning, continuous improvement, HR management, and internal promotion are required. As one interviewee confirmed:

“Employees might need to know earlier that they are going to have these technologies adopted by the company.” (Interviewee 8)

Clarifying

AVs are more widespread in organisations at this stage, as they become more visible the potential for significant resistance from internal stakeholders increases (Rogers, 2003). Hence, internal promotion of the advantages and training on how to use or interact with AVs, is vital to achieve a common understanding and trust among employees (Rogers, 2003). Continued awareness of CSR performance during technology deployment remains necessary to monitor and reduce potential SCSS risks at the operational level. As one academic mentioned the actions which are demonstrated at different AV adoption stages can vary within a category:

“When at clarifying, it is the different CSR focus you have when you are at other stages because for me, it is about measurement and not just a focus, it is much more than that.” (Interviewee 1)

Hence, the categories promotion, HR management, CSR focus, and communication

and stakeholder involvement are accompanied by a continuous improvement mindset.

Routinising

At this stage, AVs are already incorporated into the regular activities of organisations, but their long-term success and sustainability requires innovation capability to address unexpected challenges (Rogers, 2003). Therefore, technology development and change management are required for organisational transformations of operation structures, agendas, working modes, etc. (Caldarelli et al, 2021). The continuous advancement of technologies requires employees to adapt to and manage new skills and thus requires continuous upskilling and psychological support. The actions related to HR management, such as training and mental support, become crucial at the routinising stage as emphasised by multiple interviewees.

5 Conclusion

This research combined a Delphi study with expert interviews to explore and evaluate the actions that address the social implications of AV adoption and improve SCSS performance answering RQ1. The actions are categorised using an extended set of action categories and aligned to a refined Organisational IP model for Socially Sustainable Innovation Adoption of AVs answering RQ2. In combination, the identification of eight action categories and their associated actions, and how these are used to improve social sustainability leading to the IP model customised for SCSS contribute novel insights to both the social sustainability and supply chain literature as well as serving as practical mechanisms guiding managers on their socially sustainable AV adoption journeys. Corresponding theoretical and managerial contributions are drawn as follows.

5.1 Theoretical contributions

This study expands current SCSS and AV knowledge by increasing, from four to eight, the categories of actions that companies adopt to address the social sustainability implications of AV adoption in supply chains, proposing prescriptive actions. The study goes on to illustrate the value of social sustainability indicators in enabling socially sustainable AV adoption, identifying the additional context specific indicator “reputation”. The social implications for SCs seeking to follow social sustainability in AV adoption are therefore health and safety, customer satisfaction, employment, transparency, diversity and equality, welfare, and reputation.

By aligning the new action categories with the social sustainability indicators our results add a novel perspective to the social sustainability literature. Our findings answer the call for context specific indicators (Ahi and Searcy, 2015), by offering targeted solutions which address the specific SCSS challenges of AV adoption. These are highlighted in Figure 5, a context specific SCSS management framework answering RQ1. In particular, our findings add new insights to the supply chain social sustainability

literature by highlighting the nuances of managing the adoption of a technology whose adoption is characterised by social challenges. It is expected that these actions will be particularly impactful, offering a robust basis for testing other novel technologies in the move towards more general socially sustainable technology adoption in the supply chain.

In addition, this study builds on DOI theory to propose a refined IP model for Socially Sustainable Adoption of AVs. This model uses our empirical results, extending our initial model and providing a novel perspective on how the social sustainability implications of AV adoption, a technology where social concerns are fundamental to adoption, can be addressed. Figure 6 offers a novel extension of the DOI process, providing a framework that aligns our new action categories with the established stages of the innovation adoption process providing a unique insight into the practical steps taken to manage the social sustainability impacts of AV adoption as the technology adoption process progresses. Social sustainability concerns are known to vary with innovation adoption stage and this model provides a specific understanding in this context (Wamba and Queiroz, 2020). The insights gained are insightful and distinct from the original theory and our initial framework, highlighting that some of the categories, such as CSR, are important considerations that are relevant across the adoption process whereas others are specific to the Initiation or Implementation phase only. As AV adoption is particularly governed by overcoming social concerns, this model not only provides novel insights enabling socially sustainable technology innovation adoption but due to its expected comprehensive scope forms a sound basis for testing the adoption of other technologies. Finally, our findings extend current literature with guidelines for sustainable supply chain practice in technology application contexts at a strategic-level (Schilling and Seuring, 2024), as well as guidance for addressing concerns and improving supply chain social sustainability at the operational level.

5.2 Managerial implications

This study provides practical guidance for organisations who wish to address the social sustainability implications of AV adoption in their supply chains. This guidance comes from two key angles. Firstly, from a social sustainability indicator perspective, the cause-and-effect analysis in Figure 5, highlights the key categories of social sustainability concerns which are likely to arise during AV adoption with the context specific addition of the indicator Reputation. This figure provides an indicative toolset of actions that companies can use to address each of these areas of concern (social sustainability indicators), both at a strategic planning level and operationally as they arise. For example, in order to address the newly identified indicator Reputation, Figure 5 points towards key actions for mitigating reputational damage when adopting AVs. Managers can use these actions to navigate the challenges of implementing new technology in a socially sustainable way, particularly in this case ensuring they manage their reputation without impacting the welfare of their stakeholder communities. As further illustrated in Table 9, these actions highlight that to assure reputation, managers

should focus on enabling clear communication along the supply chain, ensuring that employees and other stakeholders are engaged actively in the adoption process to guarantee buy in. Managers should work with AV manufacturers to continuously improve the technology and engage technical staff to constantly manage the status of technology integration into specific company operations. CSR should be attended to by visibly checking and ensuring safety and security and managers should take responsibility for implementing these actions. In addition to keeping employees engaged, reputation can be enhanced by ensuring that they are properly trained and prepared. Promotion is key to reputation improvement ensuring that efforts are made to communicate the benefits compared to the past to affected communities such as employees, external stakeholders, and those living in areas impacted by the AVs. Trials of AVs are required to demonstrate utility and safety, particularly for drones, these should feed into further efforts to improve and provide evidence for regulation improvement.

Table 9 Actions specific to managing Reputation when adopting AVs

Category	Action
Communications and Stakeholder Involvement (CSI)	Clear communication through the whole supply chain among stakeholders (CSI-1)
	Continuous team meetings with different levels of employees (CSI-3)
	Stakeholder involvement and engagement in developing, planning, and implementation (CSI-4)
Continuous Improvement (CI)	The constant development of AV technologies (CI-1)
	AV lifecycle status transparency for better service (CI-4)
	Constant improvement via feedback loops (CI-5)
Corporate Social Responsibility (CSR)	Regular security and safety checks for reduced stakeholders' risks (CSR-1)
	Businesses to be responsible for their actions and focus on CSR (CSR-2)
Human Resource Management (HR)	Internal upskilling and training programmes to requalify the higher-skilled positions (HR-1)
	Cooperation with external training institutions (HR-2)
Promotion (PRM)	Quantify the benefits compared to the past (PRM-1)
	Promote and introduce the AVs to the public about the trial samples, the benefits and improvements (PRM-2)
	Promote to the employees for the system capabilities and interconnectivity (PRM-3)
	Promoting to the communities the benefits and risk mitigation methods (L) (PRM-4)
Real-world Experiments (RWE)	Trials of AVs to prove the concepts and benefits (RWE-1)
	Preventative measures for drone designs (L) (RWE-2)
	Tests the integration of airspaces (L) (RWE-3)
Regulation Improvement (RI)	Financial subsidies for AV operators and the AV adopters (RI-2)
	Transnational legislative approval (L) (RI-4)
	Federal guidance for adoption and certifications (L) (RI-8)

Secondly, Figure 6 offers a refined Innovation Process model for Socially Sustainable Adoption of AVs. This aligns the identified actions to the different stages of the IP process. Thus, allowing organisations to balance technological advancement with social sustainability by allowing organisations at different stages of the AV technical adoption process to identify which actions are currently required. For example, a company who has determined that AVs meet their business needs and is moving to redesign their organisational processes, needs to communicate with stakeholders so that they are aware of the plans for AV roll-out and their progress. CSR processes for

ensuring that AVs are safe and that the business operates responsibly in their deployment remain essential. Planning ensures that processes are in place such that the business environment is ready for deployment and the necessary safety measures are in place. Promotion of the benefits needs constant attention and HR continues to engage with employees to keep them informed and gainfully employed. Ideally, regulations should now have been improved to the extent that adoption is possible and trials and experiments will have been successful, so work moves to continuously developing the processes needed to support AV adoption.

From a regulatory perspective, Figure 6 highlights that the action category Regulation Improvement forms an essential element of the Initiation Phase. Regulation plays a key role in AV adoption and social sustainability concerns underpin the requirement for regulation in this context. Real World Experiments must be planned within the context of current regulation. Successful outcomes, demonstrated through the reliability of the technology in practical settings and addressing key social sustainability concerns related to Health and Safety and Reputation and Welfare, provide real world evidence to support policy-makers in updating regulations to expedite the adoption of AVs. Further, the Innovation Process model for Socially Sustainable Adoption of AVs provides a set of structured actions and social sustainability performance targets which guide organisations. Helping them in developing implementation plans to provide essential evidence demonstrating to regulators, and other stakeholders, that they are achieving SCSS performance through their actions rather than “social washing” (i.e., organisations pretend or promote to be socially responsible without acting sustainably).

5.3 Limitations and future research directions

This paper is subject to some limitations. The Delphi suffered from some attrition effects and an imbalanced distribution of experts in round 3. Whilst the study findings apply to both UAV and UGV, the application to other technologies such as AMRs needs to be tested. To date, AVs are not broadly adopted in supply chains (e.g., self-driving trucks are not yet used on public roads). Whether or not the actions with high importance ratings continue to be as relevant following full deployment needs to be further verified. This study uses DOI theory to structure the AV innovation process whilst improving SCSS performance within organisations and supply chains. The expert interviews regarding the applicability in this context was promising. However, there is a lack of understanding regarding chain-wide dynamics of multiple organisations adopting AVs and the resulting SCSS performance as a whole.

The limitations offer avenues for future research. Researchers can utilise other methods such as case studies to verify the proposed actions and models in real-life scenarios (Yin, 2018). This may prove especially fruitful once AVs are more widely adopted in supply chains and investigations could focus on the actual influence of the actions in addressing specific social impacts as well as the involvement of internal and external stakeholders. Future research can look at extending the use of organisational IP to the supply chain level by analysing how SCSS may benefit from focussing on

collaborations among organisations along the chain. The rapid development of AVs and related technologies, e.g. robotics, is likely to attract growing interest in practice. The resulting impacts and changes on social priorities and targets will necessitate updates of the action categories whilst the applicability of the developed IP model to related technologies and innovations requires verification.

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