A socio-technical approach: Facilitating the adoption of green chemistry in India's textile processing

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ABSTRACT

The textile industry relies on a series of processing steps—pretreatment, coloration, and finishing—to achieve the desired textiles properties. These processes use extensive amounts of water, energy, and chemicals, which have detrimental effects on the environment. One approach to minimise these impacts is to replace traditional chemicals with lower-impact chemicals, referred to as green chemistry (GC). Adopting GC has proven challenging, especially in developing countries, such as India. This is an area of concern given the accelerated outsourcing of textile processing to these countries owing to lower costs and less stringent regulations. Therefore, this study aimed to explore how the adoption of GC can be facilitated in India's textile processing. To do this, a qualitative study using a socio-technical approach was employed, combining both actor network theory and diffusion of innovation theory. Desk research was employed to identify 19 human and non-human actors involved in the network. This was followed by 11 interviews that were used to gather insights into actors' roles and interactions, what characteristics are required to evoke actors' interest and support, and the barriers hindering GC adoption.

The findings were used to develop six overarching recommendations made up of obligatory passage points that the actors must engage in to achieve the common goal of creating a network that facilitates GC adoption. The six overarching recommendations were meaningful collaboration, supportive governance, education reform, redefining evaluation metrics, maximising trial outcomes, and managing costs. Each recommendation enrolled the most adept actors, addressed the barriers to GC adoption, and addressed the characteristics required to evoke the actors' interest and support towards adopting green chemistry. The main takeaway of the study was that despite the urgency for change needed to address the environmental impact of textile processing, a business-as-usual mindset persists because the blame is shifted onto others for the inability to fulfill their roles. In reality, there is a systemic issue made up of a lack of commitment and collaboration resulting from a disinterest in the common objective of reducing the impact of textile processing. To facilitate GC adoption within India's textile processing, all actors must accept responsibility for their roles and work together collectively, leveraging their strengths to achieve impactful change.

EXECUTIVE SUMMARY

MOTIVATION

Textile processing has proven to have detrimental impact on the environment due the use harmful chemicals. This is significant issue in under-developed countries, such as India, where these processes are outsourced owing to lower costs and less stringent regulations. An approach to minimise this impact is to replace traditional chemicals with lower-impact chemicals, referred to as green chemistry (GC). This research aimed to explore how the GC adoption can can be facilitated in India's textile processing.

RESEARCH APPROACH

Textile processing involves a complex network of human and non-human actors with influence on GC adoption. To determine how each actors can influence adoption a socio-technical approach was employed. A total of 19 actors were identified within the network. 11 participants from the human actors identified were interviewed to gather insights into the actors' roles and interactions, the characteristics required to evoke actors' interest and support, and the barriers to GC adoption. The insights informed the final recommendations for the textile processing network.

NETWORK RECOMMENDATIONS

Currently, they're a business-as-usual mindset, with the blame is shifted onto others for the inability to fulfill their roles in facilitating GC adoption. In reality, there is a systemic issue made up of a lack of commitment and collaboration resulting from a disinterest in the common objective of reducing the impact of textile processing. Recommendations were made which enrolled actors based on the roles they were perceived to hold or their suitability. To facilitate GC adoption within India's textile processing, all actors must accept responsibility for their roles and work together collectively, leveraging their strengths to achieve impactful change

FASHION FOR GOOD RECOMMENDATION

Each recommendation serves as a critical starting point for enabling actionable steps towards facilitating GC adoption. As an industry association, Fashion for Good is positioned as a key human actor due to their perceived role in disseminating reliable information, initiating collaborative projects, and showcasing innovators. Based on these roles Fashion for Good can contribute to the following recommendations:

1. Meaningful collaborations: Mentoring processes are necessary to offer tailored support and guidance that simplify the perceived complexities around GC adoption. FFG can leverage their deep understanding of the industry and extensive network to provide invaluable support.

2. Supportive governance: Unified certifications can streamline the certification process, resulting in reduced costs and increased GC adoption by ensuring their benefits are clearly recognised. Fashion for Good can serve as a facilitator due to their ability to drive collaborative conversations and projects, enabling a common ground for the certifications to be developed.

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ABBREVIATIONS

GI – Green Innovation

GC – Green chemistry

REACH – Registration, Evaluation, Authorisation and Restriction of Chemicals

EU – European Union

ECHA – European Chemicals Agency

PFAS – Per- and polyfluoroalkyl substances

WHO – World Health Organisation

RSL – Restricted Substances List

ZDHC – Zero Discharge of Hazardous Chemicals

ANT – Actor Network Theory

DOI – Diffusion of Innovation

FFG – Fashion for Good

MSI – Multistakeholder Initiative

OPP – Obligatory Passage Point

SBP – Service-based providers

LCA – Life Cycle Assessment

BPG – Best Practice Guideline

PRSL – Product Restricted Substances List

MRSL – Manufacturing Restricted Substances List

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1. INTRODUTION

1.1 Problem statement

The environmental crisis is one of the most pressing societal challenges of our time, forcing industries to reduce their environmental footprints with greater urgency (Hens et al., 2017). This study focused on the textile industry, a global force that produces 100 billion garments per year (Apparel Impact Institute, 2021). For textiles to achieve their desired properties, they will go through all three of the following consecutive processing steps – pretreatment, colouration, and finishing (Apparel Impact Institute, 2021). These processes are traditionally classified as 'wet processing' because water is often utilised as a medium, solvent for chemical solutions, or cleaning agent between each processing step (Kumar et al., 2018). This accounts for the large volume of water and significant energy consumption needed to heat the water baths in each processing step (Apparel Impact Institute, 2021). Additionally, harmful chemicals often used in these steps leach out and contaminate water, making it one of the most polluting industries worldwide (Kumar et al., 2018; Kumar Roy Choudhury, 2017).

To minimise the textile industry's environmental footprint, the goal has been to move away from wet processing to 'dry processing' through the adoption of innovative solutions referred to as Green Innovation (GI) (Shahzad et al., 2022). GI is defined as technologies, products, or processes that aim to reduce environmental impacts (Karimi Takalo et al., 2021). Nonetheless, processing is often overlooked as a critical impact area for reducing the industry's environmental footprint, resulting in a low rate of GI adoption (Shahzad et al., 2022; Van Den Bergen & Parker, 2022). This stresses the need to critically investigate why certain barriers exist within the supply chain to develop effective strategies that facilitate GI adoption. Such measures include collaborative partnerships, better marketing strategies to encourage conscious consumption, investments in training and education, or initiatives created to raise awareness of the limitations and benefits of GI.

1.2 The case for green chemistry innovation

Within processing, GI is often categorised into two main areas: chemistry and machinery (Van Den Bergen & Parker, 2022). Chemistry refers to the chemicals applied during the processing steps, whereas machinery refers to the equipment required to execute the steps. This makes them interdependent, where one cannot exist without the other. However, both have their own set of unique considerations. Therefore, in this study, it was imperative to adopt a targeted approach that focused on only one of these areas. In doing so, the scope of the study was intentionally narrowed to ensure tailored insights could be drawn to address these specific considerations. Upon reviewing the current industry trends, the decision was made to focus on GI in the chemistry space, referred to as green chemistry (GC) throughout the study. Based on the definition of GI, GC was referred to as chemistry which has a lower environmental impact (Karimi Takalo et al., 2021).

Textile industry trends indicated that there has been a growing urgency in recent years to address chemistry-related issues over machinery owing to the primary objective of safeguarding human health and the environment. A report by the European Environment Agency (EEA) and European Chemicals Agency (ECHA), highlighted that significant advancements have been made in the identification of harmful chemical properties (European Chemicals

Agency, 2024). This has led to the restriction or prohibition of the use of specific chemicals in textiles. For example, a recent proposal submitted by Denmark, Germany, the Netherlands, Norway, and Sweden to the ECHA seeks to restrict the use of per- and polyfluoroalkyl substances (PFAS) in Europe (RIVM, 2023). This is due to the formation of carbon-fluorine bonds, which are one of the strongest chemical bonds in organic chemistry, making them highly persistent within the environment. Nonetheless, a wide range of harmful chemicals continue to be used within textile processing, stressing that the transition to GCs is imperative (Gaonkar, 2021).

Moreover, an increasing number of studies have shown that shifting to lower-impact chemistry has both economic and environmental benefits (Cardoso de Oliveira Neto et al., 2019). For example, green dyes exhibit higher exhaustion and can be used at lower temperatures, contributing to a lower dye-to-water ratio, which in turn reduces energy consumption (Saxena et al., 2017).Tayyab et al. (2019) highlighted that investments aimed at improving current processes can reduce effluent water by 12.56% and variable CO_2 emission costs by 20.98% per batch. Similarly, a report by the Apparel Impact Institute (2021) noted that shifting to mostly dry processes could potentially reduce Tier 2 emissions by up to 79%-89%.

1.3 Current research and gaps around green chemistry adoption

Existing research demonstrates a variety of frameworks for identifying barriers to GC adoption within the textile industry, a crucial step in developing strategies to allow them to scale (Xia et al., 2019). Using these frameworks, a range of barriers have been identified for the adoption of GC. These barriers include technological limitations around performance and scalability (Van Den Bergen & Parker, 2022). Additionally, due to the drop-in nature of chemicals, it is simpler for companies, such as manufacturers or brands, to switch to competing alternatives that are perceived as less time and resource intensive. Thus, making them less willing to invest or trial new GCs. Other major barriers which have been identified include regulatory restrictions, a lack of information and awareness, and shifting market demands (Rahman et al., 2019; Shahzad et al., 2022; Ullah et al., 2021; Veleva & Cue, 2019). Beyond the identification barriers, there is a growing number of research focused on identifying mechanisms which can better facilitate the adoption of GI on a broader level. However, these studies typically do not focus exclusively on mechanisms specific to GC, and they predominantly explore approaches through a financial or policy lens. This indicated a research gap in the literature regarding holistic solutions that address the multifaceted barriers which have been identified for GC. For instance, a study by (Li et al., 2022) developed a framework which specifically explores environmental taxes and the dynamics of retail competition as strategies to increase the adoption of GI in textile supply chains. Similarly, a study by (Apparel Impact Institute, 2021) provided a detailed analysis of financial models that can enhance the adoption GI aimed at reducing Scope 3 emissions. These models included bank debt, bonds, venture capital, private equity, and government or philanthropic grants.

The textile industry is global and complex, with the processing steps often spread across multiple locations. As a result, addressing barriers has proved challenging due to distinct regulations, varying levels of environmental awareness, and diverse capabilities across various regions (Manley et al., 2008; Moore & Ausley, 2004). Numerous studies have identified that these barriers are even more pronounced and challenging to overcome in less-established supply chains or developing countries, such as India (Anastas & Kirchhoff, 2002; Kumar Roy Choudhury, 2017; Shahzad et al., 2022; Veleva & Cue, 2019). This further hinders GC adoption within these regions, making it a cause

for concern given the accelerated outsourcing of textile processing to these countries due to lower costs and less stringent regulations (Moore & Ausley, 2004; Veleva & Cue, 2019). Furthermore, a further deep dive into chemical use within developing countries revealed a study by Gaonkar (2021), which explored the major chemicals of concern used in the textile industry. The study revealed that little attention has been placed on exploring the issues concerning chemical usage within India and the shift towards adopting lower impact chemicals in the literature. This underscored a significant research gap in the literature on building viable solutions for facilitating GC adoption, specifically within the Indian context where these barriers are pronounced.

Recognising the unique capabilities, regulations, and approaches to chemical usage within different regions, it is imperative to carry out tailored research that considers the unique context in which GCs are being adopted. A crucial aspect of this approach is the exploration of the intricate network of the actors involved, each of whom holds their own roles, perspectives, priorities, and conflicts of interest. For example, a company that sells garments, referred to as a 'Brand' throughout this study, is a significant driver of market trends by balancing customer expectations, cost concerns, and sustainability efforts. An 'Innovator' plays a crucial role in developing GCs, yet their success hinges on effective collaboration with brands and manufacturers to obtain the critical funding needed to carry out further R&D. While a company that creates the clothes, referred to a 'Manufacturers' is an essential partner within the supply chain by providing the infrastructure and resources needed to implement GC, although they may resist changes to their current processes due to comfort within their traditional operations. Identifying these types of dynamics amongst actors, which often extend beyond Indian borders due to the globalised nature of textile supply chains, is necessary for a deeper understanding of the socio-cultural and technical dimensions that shape GC adoption (Prosperi et al., 2020). Based on these considerations, the decision to focus on GC within the Indian context for this study was substantiated.

1.4 Research Aim

The study aimed to explore how GC adoption can be facilitated in India's textile processing. According to AKRICH et al., (2002), innovation adoption no longer depends on a single exceptionally talented individual or promising innovative technology. Instead, the success of GC adoption also requires a collaborative effort between the diverse actors involved within the processing network, where despite their differing roles, perspectives and interests, they can align their efforts to positively influence adoption. Recognising this intricate interplay between technology and societal factors, the study employed a holistic socio-technical approach (Shen & Li, 2019). This approach was drawn from both the Actor-Network Theory (ANT) and Diffusion of Innovation (DOI) theory to develop a comprehensive theoretical framework. ANT allowed for an in-depth exploration of the roles and interactions currently shaping the actor-network, and how they could be adjusted to overcome the barriers to GC adoption. Simultaneously, DOI theory served as a lens to identify which key characteristics that are required to evoke the actors' interest and support. These combined insights contributed to the final recommendations for facilitating GC adoption in India's textile processing. In the context of this study, an actor was defined in accordance with ANT as 'anything that changes a given situation by making a difference and that can influence the shaping of the network's dynamics' (Scheermesser, 2022). This underscored the importance of identifying both human and non-human actors present within the network.

The main and sub-questions of the study were the following:

Main research question:

'How can the adoption of green chemistry be facilitated in India's textile processing?'

Sub-questions:

1. *What roles do human and non-human actors hold within India's textile processing network and how do they influence green chemistry adoption?*
2. *What key characteristics are required to evoke actors' interest and support in green chemistry adoption?*
3. *What are the primary barriers hindering the adoption of green chemistry within India's textile processing?*

1.5 Scaling green innovation: The role of Fashion for Good

Owing to the magnitude of the problem, various industry associations and multi-stakeholder initiatives (MSIs) have been established over the last decade to provide opportunities for a various of activities, ranging from specific tools and guidelines to training platforms and support directories (Cristina, 2022). A prime example is Fashion for Good (FFG), a global initiative which brings together brands, manufacturers, innovators, and other key stakeholders with the goal of scaling GI that reduce the environmental impact of the textile industry (Fashion for Good, n.d.). The industry association includes an innovation platform that supports innovators on their scaling journey by providing them with access to industry experts, investor networks, and projects to validate their technologies. Positioned as an Innovation Analyst within the FFG processing team, the researcher adopted a reflective approach to systematically collect, analyse, interpret, and report data (Wittmayer & Schäpke, 2014). This was essential to develop unbiased findings, ensuring the development of actionable recommendations for facilitating the adoption of GC. As FFG's primary goal is to support innovators, these insights were significant in enhancing FFG's understanding and competence on crucial considerations for facilitating the adoption of GC, within the textile industry. Throughout the study the FFG team provided invaluable support, knowledge, and contacts to help drive the study's efforts in revealing how to how to better facilitate GC adoption in India's textile processing network.

2. BACKGROUND

2.1 Chemistry use in textile processing

Until 1856, the textile industry only used natural fibres such as cotton and wool, as well as dyes from natural sources. Then, in 1856, Sir William Henry Perkin accidentally synthesised the first commercialised synthetic dye now known as Mauve (Ban, 2006). This discovery was the turning point for textile processing as it led to the development of a range of new colours and dyeing methods. Beyond dyeing, chemicals were also developed specifically for finishing providing diverse functional properties such as oil and water repellence, or flame retardancy (Nimkar, 2018). Shown in **Table 1**, pretreatment, colouring, and finishing are the three sequential processing steps that are now a standard procedure during the manufacturing of textiles to exhibit specific functional properties and appearances (Apparel Impact Institute, 2021).

Processing Step	**Pretreatment**	**Colouration**	**Finishing**
Description	The process of cleaning the fibre to make it more receptive to the chemicals in the subsequent steps.	The process of applying dyes onto textiles to achieve a desired colour.	The process of applying a treatment to a textile to give it a specific desirable quality or functionality, making it better suited for the intended use.
Function	(De)sizing, Scouring, Bleaching, Neutralization, Mercerizing, Optical Brightening, Biopolishing	Dyeing, Printing	Fixing Chemistry, Heat Setting, Stain resistance, Durable Water and Oil Repellence (DW(O)R), Antimicrobial, Biopolishing, Flame retardancy, Easy care, Softening, Antistatic, Improved handle

Table 1: Processing steps and Function

An overview of the three consecutive processing steps and their function.

Source: Based on Van Den Bergen & Parker. (2022)

2.2 The emergence of green chemistry within textile processing

Within the textile processing, each step uses various chemical combinations, each often raising their own set of concerns to health of humans and the environment. While the negative impact of chemicals used has long been recognised, concrete attention to them only began in the 1990s due to the growing body of research conducted by actors within the industry and scientists (Nimkar, 2018). As awareness increased, industry actors including regulatory bodies, brands and more started taking concrete measures towards producing lower impact textiles. For example, brands implemented Restricted Substances Lists (RSLs) to minimise the use of harmful chemicals in their products. Additionally, MSIs like Zero Discharge of Hazardous Chemicals (ZDHC), developed certification frameworks to help verify the chemicals within products; many of which have now been embraced by brands within their approach for selecting manufacturers as their suppliers. Moreover, new regulations were developed that enforced compliance to certain requirement to sell products in specific regions of the world. One example is the Registration, Evaluation, Authorization and Restriction of Chemicals regulation (REACH), which requires companies that produce more than one tonne of chemical compounds per year to register with ECHA (European Commission, n.d.). Currently, companies must report the risks connected to the chemicals they handle as well as their risk management practices in accordance with REACH regulations.

Due to increasing awareness and stricter chemical management strategies implemented over time, a proliferation of GCs were developed (Manley et al., 2008b). **Table 2** includes examples of GCs that have been developed to replace traditional chemicals used in each processing step.

Processing Step	Green chemistry	Function	Benefit over traditional chemistry
Pretreatment	Cationic treatment	Cotton is altered to have a cationic, or positive charge. This makes the cotton more receptive to any subsequent chemicals.	Replaces the use of harmful chemicals used in traditional pretreatments acids (i.e., caustic soda) and surfactants. Additionally, as the cotton is more receptive to subsequent chemicals, this means less of them are required, which ultimately also decreases the amount of water and energy needed for the subsequent processing steps.
Pretreatment	Enzymatic treatment	Enzymes are used to alter the fabric to become more receptive to any chemicals in the subsequent steps.	Replaces the use of harmful chemicals used in traditional pretreatments like acids (i.e., caustic soda) and surfactants. Additionally, as the fabric is more receptive to chemicals, this means less of them are required, which ultimately also

			decreases the amount of water and energy needed for subsequent the processing steps.
Colouration	Natural dyes or pigments	Natural sources such as algae and plants are used to colour the fabric. T	Minimises the reliance on synthetic chemistry traditionally used for pigments and dyes.
Colouration	Microbial pigments	Microbes are multiplied by feeding them sugar and other feedstocks via fermentation. The pigments are then extracted and used for colouring the fabric.	Minimises the reliance on synthetic chemistry traditionally used for pigments.
Colouration	Dyes from carbon capture	The use of carbon emissions as feedstock to make dyes.	Minimises the reliance on synthetic chemistry traditionally used for pigments and dyes.
Colouration	Recycled dyes	The use of textile waste to make dyes by transforming the waste into a finely crystalised powder or chemically recovering dyes from pre- or post-consumer waste.	Uses textile waste as a feedstock which minimises the reliance on synthetic chemistry and employs a more circular principle to producing dyes.
Finishing	PFC free DW(O)R chemistry	The use of chemicals containing silicone or bio-based solutions (e.g. waxes, wood etc.) which impart durable water (and oil) repellence properties.	Minimises the use of PFCs which are persistent in the environment and toxic to both human and environmental health.
Finishing	Biobased antimicrobial chemistry	Chemicals containing antimicrobial polymeric components, such as chitosan, are utilised. These components originate from bio-based	Minimises the use of heavy metals (silver, copper and zinc) traditionally used in antimicrobial finishes. These metals often leach into water and are proven to be hazardous to both aquatic life

	sources, such as flax and wood, as well as waste from the seafood sector, such as crab or shrimp shells.	and humans when ingested or exposed to the skin.

Table 2: Green chemistries examples

An overview of examples of green chemistries developed as alternatives to traditional chemicals used within each processing step, along with their function and benefits as replacements.

Source: Based on Van Den Bergen & Parker. (2022)

Table 2 provides an overview of the GC examples which have been developed as lower-impact alternatives. However, it is important to recognise that that GCs belong to an ever-evolving field, continually challenges innovators to consider technological elements that address the sole function of the chemical they are replacing, as well as the needs of its adopters. In textile processing, the goal is to develop chemicals that meet industry performance requirements from manufacture to end-of-life, while minimising environmental impact. For example, the use of viable PFC-free DW(O)R chemistry has become increasingly widespread due to the variety of GC alternatives that have been developed in response to the growing body of research, legislation, and certifications urging the phase out of PFAS. This reflects the dynamic nature of GC development and adoption within the industry.

3. THEORETICAL FRAMEWORK

3.1 Socio-technical approach

Innovation and technology adoption studies have evolved significantly in recent decades (Banker & Kauffman, 2004). Initially, during the 1950s and the 1960s, the notion was that technological progress dictated the trajectory of how processes and operations evolved. This perspective was influenced by social scientists such as Thorstein Veblen, who credited technological progress for humanity's development from the stone age to the industrial revolution. However, by challenging this notion, theories emerged that balance the impact of technological and social factors equally. These more holistic theories adopt a socio-technical approach, which emphasises the co-evolution and mutual adaptation of society and technology. This highlights the fact that social behaviours necessitate a certain degree of technology adaptation in order to adapt to societal needs, and that technology adoption itself causes some degree of societal change (Amuzu-Sefordzi et al., 2018). For example, in the context of GC, Microbial pigments are derived from microbes, reducing the reliance on harmful chemicals and synthetic pigments. This reduces environmental impact and directly addresses the growing environmental concerns among consumers, or aligns with increasing regulatory pressures for more sustainable dyeing methods. However, the adoption of microbial pigments also requires specialised equipment and methods. This in turn necessitates workforce to develop new skills and training.

The socio-technical approach recognises the dynamic and nonlinear nature of innovation adoption, characterised by iterative changes that are influenced by the interactions of the actors involved in the development of the innovation. (Aka, 2019; AKRICH et al., 2002b; Dodgson et al., 2013). Socio-technical literature describes this as a relational process that relies on the collective efforts of many actors within the supply chain. Therefore, the success of adoption hinges on the convergence of these actors' interests, ultimately creating a network in which innovation is perceived as favourable. The purpose of this study was to explore how the adoption of GC can be facilitated in India's textile processing by developing a socio-technical theoretical framework that incorporates elements from both ANT and DOI. These theories shed light on the roles and interactions between human and non-human actors within the network, the characteristics necessary to evoke actor's interest and support towards GC adoption, and finally the barriers that are currently hindering GC adoption. This integration highlighted the dynamic interactions between the innovation's technological and sociological components, leading to the development of recommendations (outlined in **Section 6**) for facilitating GC adoption (AKRICH et al., 2002b). **Figure 1** illustrates the theoretical contributions from both ANT and DOI within the framework.

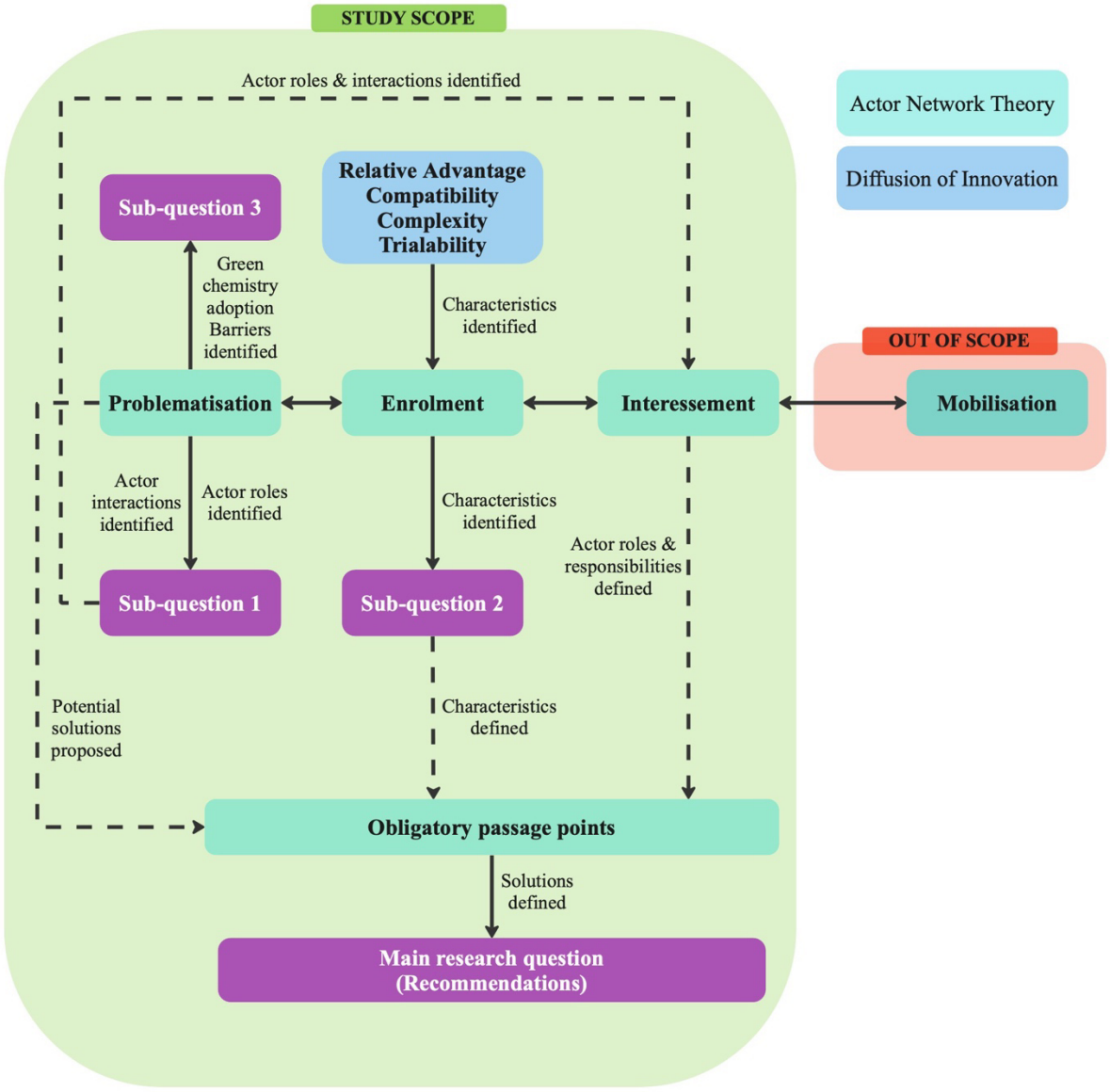

Figure 1: Socio-technical theoretical framework

Conceptual diagram showing the theoretical contributions of the Actor Network Theory (green) and the Diffusion of Innovation Theory (blue) for each sub-question and main research question. Problemitisation was operationalised to identify the actors' roles and interactions within the network for sub-question 1, to identify barriers to green chemistry adoption for sub-question 3, and to reveal potential solutions for the main research questions. For sub-question 2, the diffusion of innovation criterion were operationalised to contribute to enrolment, identifying the characteristics required to evoke actors interest and support. Interressement was operationalised by defining the actors' roles and responsibilities within the network that would be assigned to the actors' whom willing to accept them or most suitable for them. Mobilisation was beyond the scope of the study. Bold lines in the diagram represent data directly answering the sub-questions, whereas dotted lines indicate how data informed the main research question.The link to the figure can also be found in ***Appendix V.***

ANT provided a nuanced examination of the roles and interactions among the human and non-human actors, addressing sub-question 1. For example, 'Multi-stakeholder initiativess' (key human actors) develop chemical standards for certification (outlined in **Section 5.1.2).** These certifications (key non-human actors), are crucial for the industry as they serve as a formal acknowledgment of adherence to industry requirements (outlined in **Section 5.1.4**). Additionally, ANT was used to uncover the current barriers hindering GC adoption, addressing sub-question 3. For example, the lack of standardised frameworks for certifications fail to adequately recognise the unique environmental benefits of different GCs, creating hesitancy to adopt GC as they are perceived as unrecognised products (outlined in **Section 5.3.1**). Concurrently, DOI served as a lens to analyse the characteristics required to evoke actors' interests and support towards GC adoption, addressing sub-question 2. For instance, there was an preference for simplyifying processes by minimising the additional training and knowledge required within the workforce to reduce the perceieved complexity of GC adoption (outlined **in Section 5.2.4**). Together, the insights derived from answering each sub-question informed the final recommendations that addresseed the main research quesitons– *'How can the adoption of green chemistry be facilitated in India's textile processing?*'. Each recommendation was made up of obligatory passage points (OPPs), a key concept within ANT. OPPs refers to crucial steps that various actors must engage in to achieve a common goal. In the case of this study, the goal creating a network that facilitates GC adoption.

An interview guide was designed based on this theoretical framework to draw data that addressed each research sub-question. **Appendix I** provides the interview guide structured into four sections: 1) Participant introduction and problem definition, 2) Actor roles and interactions, 3) Barriers and solutions, and 4) Characteristics of GC. The use of the interview guide is further elaborated in **Section 4.3.2** of the Methodology, and the granular contributions of both theories within the framework are explained further in **Section 3.2** and **Section 3.3**, respectively.

3.2 Actor-network theory

French sociologists Michel Callon and Bruno Latour's work gave rise to ANT in the 1980s as a conceptual framework for researching socio-technical processes and understanding how scientific knowledge was produced and adopted (Bencherki, 2017). It has now evolved to be used as a systematic approach to explore the process of innovation adoption (Cresswell et al., 2011; Zein et al., 2022). ANT underlines that innovation adoption involves complex interactions between human and non-human actors in a heterogeneous network (McBride, 2023). The emphasis on exploring the dynamic and relational aspects of the network makes it a valuable lens for studying phenomena such as GC adoption (Zein et al., 2022).

In ANT, an 'actor' is defined not by whether it's human or non-human, but by its ability to influence the outcome of the network, irrespective of its nature. This influence is seen as relational as it stems from the interactions with other actors within the network (Bencherki, 2017). Therefore, it is the task of the researcher to determine what should be categorised as an actor based on whether it influences the network. Human actors shape the innovation process through their representations, interpretations, interests or demands (Aka & Labelle, 2021). These can be individual humans or a group of individuals working collectively within society. For example, a regulatory body – is a group of individuals – who enforce laws aimed at reducing environmental impact of operations. This influences other actors' behaviours and functions within the network. Whereas, although non-human actors are often either

created by human actors or shape human actions, they also have influence on the network through their quality, physical or non-physical natural properties, or constraints. This means they influence the outcome by enabling, blocking, or changing the way of doing things (MacLeod et al., 2019). For instance, certifications are a non-human actor created by MSIs. As outlined in **Section 5.1.9**, they serve as an indication of quality, safety, or environmental impact. However, the study revealed current certifications do not adequately recognising the unique environmental benefits of different GCs (refer to **Section 5.3.1**). When they fail to recognise GC as viable alternative, this negatively influences the adoption of GC as this creates hesitancy to switch from the traditional chemicals as they are perceived as unrecognised products. The key take-away from this is that both types of actors play active roles and interact with each other in various ways within the network.

The central concept in ANT is the translation process, where the diverse actors within the network align with the focal actor towards the common goal (McBride, 2023; Pablo & London, 2016). This process is dynamic and unfolds in four movements: problematisation, interessement, enrolment, and mobilization (Tatnall & Burgess, 2011). As represented in **Figure 1**, these translational movements do not occur in a linear sequence, but rather interconnect and swirl back and forth like a whirlwind (AKRICH et al., 2002b). This dynamic nature corresponds to the iterative changes driven by the continous interactions of the actors, with each movement reinforcing or reshaping the outcome of the network (Aka, 2019; McBride, 2023).

Problematisation is the process in which a focal actors define the problems, and the roles of the actors with influence on the network's outcome (Tatnall & Burgess, 2011; Zein et al., 2022). A focal actor can be numerous actors, often managers or decision-makers with insight into the adoption process. The focal actors also propose potential solutions. By doing so, the focal actors become indispensable to the network, guiding other actors to engage with the solutions they propose. These proposed solutions contributed to the final OPPs - crucial steps that various actors must engage in - highlighted within the recommendations of the study in **Section 6**. For example, **Section 5.1** of the study highlights that brands often serve as human actors responsible for covering trial costs. However, **Section 5.3** identifies a major barrier was brands' reluctance to incur these costs. To overcome this, a consultant that was interevieweed within the study proposed the development of a pilot fund. The consultant emerged as a focal actor within the network, as they leveraged their understanding of the network to propose the pilot fund which would enable more trials while reducing the finical burden by distributing costs. Recognising the potential of the pilot fund in facilitating GC adoption, this solution was adopted into the final recommendations of the study as one of the OPPs for 'Maximizing Trial Outcomes', outlines **in Section 6.5**.

Interessement is the process of evoking actors' interest and support and convincing them to accept their roles within the solutions proposed (Tatnall & Burgess, 2011; Zein et al., 2022). This entails identifying various characteristics that evoke interest and support, such as the inherent characteristics of a GC or activities (including processes, mechanisms, or actions). Once identified, these can be leveraged, addressed, or incorporated within the final OPPs to increase the likelihood of GC adoption. For example, in **Section 5.2** 'Trialability' was identified as a high interest characteristic due to its ability to produce favourable results. However, minimising 'Complexity' associated with trials was also identified as high interest. Therefore, the adoption of a pilot fund as an OPP was further

supported because it directly reduces the perceived complexity of trials by facilitating collaborative resource and capability sharing among the actors involved.

Enrolment is the process by which each actor's roles and responsibility are defined and accepted to transform a hypothetical network into an actual network (Tatnall & Burgess, 2011; Zein et al., 2022). During this process, it involves actively recruiting both human and non-human actors, winning their commitment, and mobilizing them to participate in the network's activities to achieve the common goal (Carroll, 2018). For instance, in the creation of the pilot fund, enrolment requires the active participation of trials, manufacturers, brands, and regulatory bodies. Each actor must understand and accept the benefits derived from their involvement, which further encourages their commitment and mobilization. This is essential for driving the success of the pilot fund and the development of similar structures. The specific roles and benefits for each actor within pilot funds is elaborated in **Section 6.5**.

Finally, mobilization is the process in which the proposed solutions gain wider acceptance, and the actors are successfully enrolled to create a stable network (Aka, 2019; Zein et al., 2022). In this study, a stabilised network facilitates the adoption of GC within India's textile processing. In such a network, actors' interests align, and they are prepared to participate in specific methods of thinking and actions to sustain the network (Zein et al., 2022)**.** Due to the nature and duration of the study, Mobilisation was not operationalised within the study's scope as it was not possible to assess the wider acceptance of the solutions proposed.

Table 3 illustrates how the movements of translation were operationalised to inform the study. Further examples of the questions used to operationalise each movement are found in Sections 1-3 of the interview guide in **Appendix I**.

Movement	**Operationalisation**
Problematisation The process in which a focal actor defines the problems, and the roles of the actors with influence on the network's outcome.	Questions were asked to **identify actors' roles and interactions** using interview questions, such as: • Please introduce yourself and your role at ____? • Who do you typically interact with ___? • What roles does ____ have on the adoption of GC? • How does ____ influence GC adoption? • Can you describe the typical process by which GC is introduced? <u>Example finding:</u> An interviewee from an academic institution noted, "we *incorporate topics into the syllabus related to environmental management, utility conservation, waste management, sustainability, and circularity*". This highlighted their role in imparting education within the textile processing network.

	Example finding: An interviewee from a brand noted, "*I think we have a better ear on the ground than* regulatory bodies *do"*. This revealed a perceived disconnect between regulatory bodies and the rest of the network, indicating their interactions within other actors is somewhat limited. Questions were asked to identify **barriers to GC adoption** using interview questions, such as: • What are the main barriers to GC adoption? • What actors have you encountered most resistance or challenges with? • Have you faced any challenges with____ (e.g., certifications)? Example finding: The participants all explicitly highlighted cost as a key barrier. An interviewee from an academic institution stated, "*Cost and the performance".* An interviewee from a brand stated, *"It's always cost".* Questions were asked to **identify potential solutions** to overcome each barrier using interview questions, such as: • What solutions have you/can be implemented to address this? • How have you personally addressed this barrier? • Can you give me examples of the type of tools or strategies that can help incentivise GC adoption? Example finding: Various participants indicated financial support from regulatory bodies as a solution to encourage further investments into GC. An interviewee from a brand pointed out that "*Brands are incentivised by profitability and market share – they are very financially driven...it could be in the form of a subsidy".*
Interessement The process in evoking actors' interest and support is generated, convincing them to accept their roles within the solutions proposed.	Characteristics to evoke actors' interest and support were identified using the four criteria of The Diffusion of Innovation theory. (Refer to **Section 3.3**)

Enrolment The process in which each actor's roles and responsibilities are defined and accepted to transform a hypothetical network into an actual one.	Implicit answers were drawn to **define the actors' roles and responsibilities** by assigning them to actors' based on two criteria: • Willingness to Accept: Actors who explicitly expressed their willingness to take these roles. • Suitability: Actors recognised as being ideally suited for the roles due to their influence, resources, or capabilities within the network. Example finding: There was consensus among the participants that brands are most suited for the role of covering the costs associated to GC due to the purchasing power they hold within the network. An interviewee from an industry association highlighted, "*brands will enable or pull the adoption given that premium pricing will only be invested in if the brands are willing to adopt*."

Table 3: Operationalisation of the Actor-Network Theory

The operationalisation of the three movements of translation used within the theoretical approach: Problematisation, Interessement, Enrolment, and Mobilisation.

Source: Based on (Aka, 2019; Tatnall & Burgess, 2011; Zein et al., 2022).

3.2.1 Actor considerations

The first consideration is that ANT expands our understanding of how the network operates by ensuring that analytical attention is given equally to non-human and human actors. This approach avoids treating non-human elements as tools or passive components of the network (MacLeod et al., 2019). However, it's important to acknowledge that while human actors can directly communicate their experiences and intentions, non-human actors do not have the abilty to speak. Therefore, to analyse non-human actors it requires the researchers to interpret the influence of non-human actors on other actors through the perceptions of the human actors themselves (Kennan, 2010). The inevitable limitation of this it that it can cause non-human actors to be underrepresented or important dynamics to overlooked. To minimise this, the first phase of the study involved collecting secondary data through desk research, which helped in developing a map that included both non-human and human actors within the network. This map was then validated and expanded upon through further during primary data collection to ensure a thorough representation of non-human actors leading to the final map illustarte in **Figure** 5. Details of this approach are further elaborated in **Section 4** of the study.

The second consideration is that within ANT, an actor is defined as its ability to influence the outcome of the network (Bencherki, 2017). In determining this, the level of influence will also be revealed. Therefore, the decision was taken to differentiate actors between key and supporting actors within this study. This does not mean that supporting actors were be given less analytical attention. The actors described as key actors were those with the most influence within the network, making their roles essential for the adoption of GC. The actors described as supporting actors were those that still play crucial roles in GC adoption, but their influence within the network was perceived as

less significant for various reasons. For example, as outlined in **Section 5.1.3**, service-based providers (SBPs) were revealed to be essential for providing testing and interpretation services. This requires them to maintain impartiality in the rest of the network to provide unbiased and reliable results. Therefore, their influence on GC adoption within the network is limited, positioning them as supporting actors. The reasons for positioning each actor as either a key actor or supporting actor will be elaborated throughout the analysis in **Section 5**.

3.3 Diffusion of innovation theory

DOI theory, developed by E.M. Rogers in 1962, states that the perceived characteristics of an innovation, the characteristics of adopters, and the social and cultural context in which innovation is introduced all influence innovation adoption (Rogers, 2003). Therefore, this interplay between society and technology during the adoption process gives rise to disruptions, manifesting as either positive or negative changes in the social systems of adopters (Wilson, 2018). In the context of the textile processing network, the adopters encompass all the human actors within the network. Whether positive or negative – adoption will lead to each having to navigating changes in some type of form. Positive disruptions refer to the benefits an innovation brings that enhance the well-being and socio-economic status of adopters. For example, a positive disruption may occur when a brand adopts GC. This adoption can enhance the brand's reputation and facilitate access to new markets that prioritise sustainability, driving financial benefits. Conversely, negative disruptions refer to perceived sacrifices or trade-offs necessary for innovation adoption. For example, a negative disruption may involve changes required by manufacturers, such as replacing or modifying machinery to accommodate the requirements of GC, requiring capital investment and disruptions to current processes. This perspective underscores the idea that the impact of an innovation varies across networks, emphasizing the need to assess adopters' perceptions of the characteristics associated with an innovation.

DOI theory proposes five criteria: relative advantage, compatibility, complexity, trialability, and observability (Rogers, 1962). According to DOI theory, 'Trialability' is the extent to which an innovation can be tested and familiarised before committing to its adoption, while 'Observability' is defined as the extent to which the outcome of the innovation is visible and communicable to others. For this study, the criteria Trialability and Observability were merged into one criterion referred to 'Trialability'. This decision was made based on the understanding that 'Trialability' inherently encompasses 'Observability', as the process of testing GCs at a limited scale (often through Trials and Life Cycle Assessments (LCA)) is conducted with the intention to make the outcomes of a GC visible and communicable to others. The final definitions of the four-criterion of DOI used wihtn the study and their operationalisation are shown in **Table 2** below. Further examples of the questions used to operationalise movement are found within Section 4 of the interview guide in **Appendix I**.

Criterion	Operationalisation
Relative Advantage The extent to which an innovation is perceived to be better than the idea it supersedes.	Questions were asked to determine which characteristics were perceived **as a relative advantage**, such as: • What do you think is the relative advantage of GC? • What are the added values a GC should hold to be adopted? • Can you provide an example of the added value observed from a GC you have adopted? Example finding: An interviewee from a manufacturer noted, "*I don't think I have to say anything about the green chemistry's added value from the perspective of the environment. I think, that is self-explanatory*". The reference to "*self-explanatory*" captures the broad consensus among the actors that the relative advantage of impact savings is both clear and widely acknowledged.
Compatibility The extent to which an innovation is perceived as consistent with existing values, past experiences, and users' needs.	Questions were asked determine the perceived **significance of compatibility** of GC to be adopted, such as: • How important is it for GC to be compatible with current processes/machinery? • Implicit answers were drawn on significance of compatibility of GC, when discussing the barriers to GC adoption. Example finding: A consultant noted, "*it needs to not have any incompatibility issues. Any technology that is more compatibile, is more likely to be adopted*". This explicitly highlights the significance of compatibility.
Complexity The extent to which an innovation is perceived at relatively difficult to understand and use.	Questions were asked on the perceived **complexity** of adopting GC, such as: • Do you find GCs easy or complex to adopt? Why? • Implicit answers were drawn on the **complexity** of adopting GC, when discussing the challenges surrounding trials and the barriers to GC adoption. Example finding: An innovator stated "*people are often resistant to change, even for minor adjustments. This resistance stems from a need for simplicity in processes, especially since many operators may not be extensively trained*". This directly underscored the need for simpliyfing processes by minimal additional traning to the workforce to reduce the perceieved complexity of GC adoption.

Trialability The extent to which an innovation can be tested and familiarised to show the outcome of the innovation to others.	Questions were asked on the perceived **value of testing GC through trials**, such as: • Is there a value of conducting trials on GC? Why? <u>Example finding:</u> An innovator explitly states, "*conducting trials is indispensable",* emphasing the significant value of carrying out trials.

Table 4: Operationalisation of The Diffusion of Innovation Theory

Operationalisation of the four criteria from the diffusion of innovation theory used to identify the characteristics required to evoke actors' interest and support towards green chemistry adoption

Source: Based on (Rogers, 2003)

In the literature, relative advantage, compatibility, and trialability are all positively correlated with innovation adoption (Kapoor et al., 2014). However, complexity is negatively correlated with adoption. These correlations are attributed to the perceived positive and negative disruptions they bring to adopters. For instance, price advantage was identified as a key characteristic perceived as a relative advantage. Therefore, as noted by consultant, a GC is more likely to be adopted by an Indian manufacturer if it proves to reduce the amount of "*salt which needs to be recovered... as this will automatically reduce the amount of energy and then there will be cost savings".* Conversely, a negative disruption occurs if a GC is incompatible with existing machinery and requires adjustments that can lead to disruptions within current operations. Utilising these criteria was pivotal for recognising and understanding which characteristics needed to be leveraged or addressed to within the the final OPPs, outline in **Section 6**. The characteristics associated with negative disruptions revealed barriers that needed to be addressed, pointing to alterations required concerning those characteristics or solutions that needed to be created to compensate for them. Meanwhile, characteristics linked to positive disruptions revealed opportunities to leverage to evoke actors' interests and support. The insights drawn from DOI theory were instrumental in contributing to the characteristics required in the movement of 'Interessement' within the ANT, which concerns eliciting interest and support from actors within the network.

4. METHODOLOGY

4.1 Research design

The study employed a qualitative approach as it offers a more open-ended and flexible approach required for areas of studies in which little is known – as was the case for this study owing to the lack of research on GC adoption within the context of India (Bryman, 2003). Semi-structured interviews were used due to their interpretive nature, allowing data to be drawn that uncovered the complex dynamics between the actors, as well as reveal each actors' perceptions, interests, and experiences. This was crucial to answer questions concerning the 'what', 'how' or 'why' the phenomenon exists, gaining better understanding of the status of network and why certain GC adoption barriers exist (Yin, 2013). Lastly, qualitative research places an emphasis on understanding behaviours within its specific context. This was another critical aspect to the study, considering the regional and chemistry related nuances that play a pivotal role in shaping the network's dynamics (Bryman, 2003). This context-specific approach was vital for developing actionable recommendations which not only resonated with the actors involved, but also tailored to the unique challenges and opportunities present within India's textile processing.

The use of case study was chosen as according to Yin (2013), they are most appropriate for investigating phenomena in depth within real-life contexts. Moreover, they are helpful in providing information about specific challenges, particularly in circumstances when it is difficult to find exact solutions (Gustafsson, 2017). The use of a single case study was deemed appropriate, given the complex nature of textile supply chains and the multitude of challenges associated to GC adoption. Therefore, this approach was favoured over a multi-case one, as it allowed for a more in-depth understanding into the specific challenges to GC adoption and formulating potential solutions, rather than attempting to understand how the situation differed from other cases (Baxter & Jack, 2015).

As depicted in **Figure 2**, the study was split into three phases. In phase one, secondary data was obtained through desk research, contributing to the development of the relationship map of non-human and human actors within the network. This map served for two functions: first, as reference for sampling participants from each actor group, and secondly it was iteratively developed throughout the study to visualise the actors, their roles, and interactions within the network (Interact for Health, n.d.). In phase two, primary data was collected through semi-structured interviews and analysed in a continuous process to allow for a more accurate comparison of codes. For the data analysis, both an inductive and deductive approach was employed (Steenhuis & De Bruijn, 2006). The deductive method was applied, categorising the collected data into categories based on the theoretical frameworks outlined in **Section 3**. Specifically, data were categorised with the four criteria of the DOI (relative advantage, compatibility, complexity, and trialability), and the concepts that aligned with ANT (actor's roles and interactions, barriers to GC adoption, and potential solutions). Whereas the inductive approach was used to stay open to new emerging themes and concepts influencing GC adoption. This was necessary as little was known about the phenomenon of GC adoption. Lastly, in phase three, the sub-questions and the main research question were answered using the insights gathered.

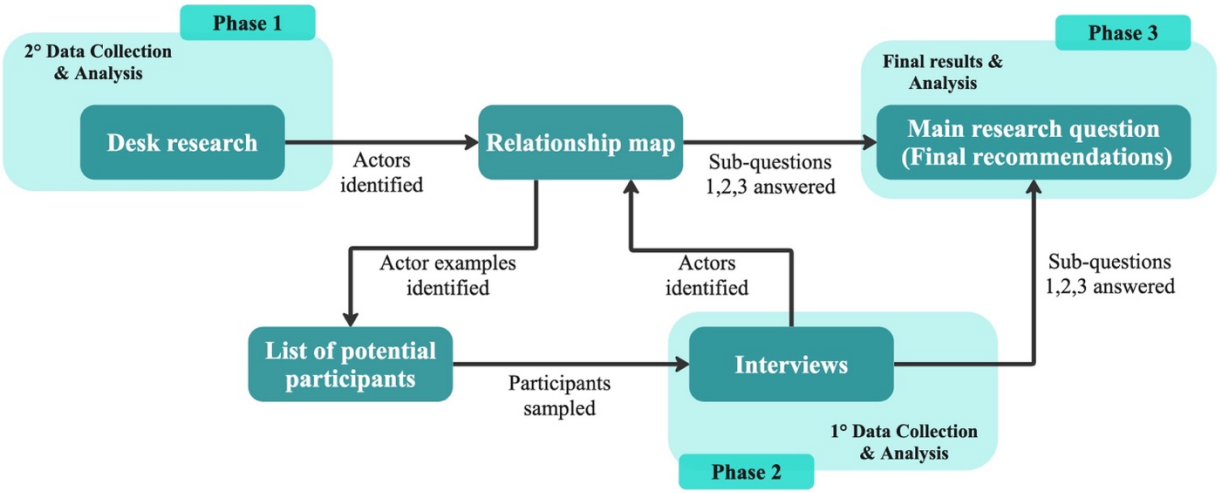

Figure 2: Research Design

Flow diagram depicting the three phases of the research design. In phase 1, secondary data was obtained through desk contributing to the development of the relationship map of non-human and human actor. The map was used to create a list of potential participants and to answer the sub-question. In phase 2 of the study the interviews were conducted to collect primary data. The data was used to answer the sub-questions. In phase three, the sub-questions and the main research question were answered using the insights gathered. The link to the figure can also be found in ***Appendix V.***

4.2 Data collection

4.2.1 Secondary data

The secondary data was collected through desk research using both FFG's internal sources and internet sources. The first layer of secondary data aimed to identify human and non-human actors within India's Textile processing network. Firstly, FFG's internal sources were leveraged due to the extensive network of actors FFG typically engage with. Next, various internet sources were accessed such as academic publications, government websites, and industry reports. Targeted search terms such as 'India's textile processing network,' 'Actors involved within textile processing,' and 'green chemistry adoption in India' were used. **17** actors were identified and inserted onto a table on Excel to keep the data search consistent and replicable for future research. The data triangulation of internet sources with FFG's internal sources served to validate and ensure greater confidence in the actors identified (Bryman, 2003). **Appendix II** includes a table that resembles the one made on excel, which was then used to create the relationship map. The second layer of secondary data aimed to identify real-life examples for each actor. A similar process was repeated - accessing FFG's internal sources, followed by internet sources. This time the criteria selection was the explicit mention of the actor's involvement in at least one of the processing steps - pretreatment, dyeing, and finishing. For example, the search term "Textile manufacturers in India" was used both within FFG's internal sources and internet sources to find **21** real-life examples of manufacturers. This included Manufacturers such as Arvind Limited, Welspun India Limited, and KG Fabrics. In ***Appendix III*** the link to the original excel document

can be found which shows the tables made for each actor. Each table also includes the process and search terms used to identify each real-life example and the reason for inclusion.

4.2.2 Primary data

The primary data was gathered through semi-structure interviews. The open-ended, exploratory questions encouraged participants to discuss their experiences and perceptions freely, facilitating descriptive data to be obtained. This is a common approach in qualitative research as it allows in-depth insights to be gathered on the participants' behaviours, attitudes, and experiences to better understand the phenomena through the perspective of the interviewees (Boeije, 2009). A total of **11** semi-structured interviews were conducted online between the 24th of January 2024 to the 7th of March 2024. Each interview lasted between 45 to 60 minutes and was recorded and transcribed. **Appendix I** provides the interview guide used throughout the interviews which was designed based on the theoretical framework outlined in **Section 3** to draw answers for each of the research questions. The interview guide was structured into four sections: 1) Participant introduction and problem definition, 2) Actor roles and interactions, 3) Barriers and solutions, and 4) Characteristics of GC. Prior to each interview, questions were tailored based on the data obtained from earlier interviews and in consideration of the participant being interviewed. Given the less-established chemical standards in comparison to developed countries, it was anticipated that potential barriers to primary data collection included participants' reluctance to disclose sensitive information regarding their current practices to ensure safe chemicals usage and their stance on the urgency of GC adoption. To minimise this and ensure reliable data was obtained, trust was established with each participant through various methods, outlined in **Section 4.5**.

4.3 Sampling approach

4.3.1 Actor sampling

The first level sampling involved narrowing down the list of real-life examples associated with each human actor to two or three per actor as they would be used to select participants from for the interviews. This was only necessary for the human-actors as they have ability to speak. The initial selection was based on examples that appeared in both FFG's internal sources and internet sources, employing data triangulation to confirm their involvement in India's textile processing industry. If direct involvement was not evident from internet sources, validation was sought from FFG team members who have extensive experience and engagement with actors within the textile industry. This was particularly necessary for brands, as their supply chain presence was often not transparently visible online. The actors identified through this process were then used to select participants for the study. To maintain confidentiality, the final sample of participants has not been disclosed.

4.3.2 Participant sampling

The second level of sampling employed purposive sampling to ensure that participants were chosen based on their knowledge and experiences, ensuring that the primary data collected was relevant to the study (Patton, 2014). Potential participants were identified from the examples associated with each human actor identified in **Section 4.3.1,** and then the inclusion criteria included:

a) Two years' experience in the textile sector

b) One year's direct experience in India's textile processing

c) Direct experience with GC

d) English competence, given the study's capacity and money for obtaining an interpreter

Within the study, 'experience' is defined as holding a decision-making position, such as an executive, CEO, or manager responsible for overseeing daily operations that affect strategic choices. This criterion was necessary to identify participants capable of serving as focal actors within the network, ensuring that they had visibility on the actors the dynamics within the network and an understanding of current barriers to GC adoption. Thus, equipping them to propose potential solutions which contributed to the final OPPs developed within the recommendations of the study. This approach aligns with ANT, which considers such focal actors as 'indispensable' for their role in shaping the network guiding other actors to engage with the proposed solutions to reach a common goal. For innovators, 'experience' were gained through formal employment, but also through projects, collaborations, or ongoing conversations pertaining to the adoption of their GC within India, given their relatively new presence within the industry.

Outreach leveraged FFG's extensive network to facilitate introductions. FFG has established trusted relationships and a solid industry reputation due to the numerous projects it has managed with industry actors. Therefore, it was anticipated that introductions through FFG would minimise any trust-related hurdles that could jeopardise the validity of the results and the willingness to participate. An example is the *Dyestuff Library* Project which involves validating dyestuff innovations through running trials and impact screenings. Other projects include providing targeted support to suppliers while implementing market-ready innovation. Bias from pre-existing interrelationships was minimised by using the actors identified through the desk research to guide which actors and participants needed to be approached to obtain a representative sample, rather than solely relying on FFG's network. LinkedIn was used to contact those whose contacts could not be provided through FFG. Lastly, a snowball sampling strategy was employed to reach hard-to-reach participants via participant acquaintances, ensuring a representative sample (Atkinson, 2001). The final sample was comprised of **11** participants. **Table 5** provides an overview of the participants interviewed within the sample and the reason for their inclusion.

Actor	Reason for Inclusion	Location
Manufacturer: Senior Management	Included as the participant is a Senior Manager at a vertically integrated manufacturer. This makes the participant a key decision-maker on the chemistry used in all processing steps carried out in the facility, offering insights into the operational considerations and challenges of adopting new chemistry within a manufacturing setting.	India
Industry Association: Innovation Director and Head of Asia	Included as the participant is involved with an extensive network of the textile industry, providing a direct perspective on the interactions and interests of the various actors involved within the scaling process.	Netherlands
Brand (Small): Technical Manager	Included as the participant provided a unique viewpoint on the challenges and operational dynamics specific to a smaller brand in the industry.	United Kingdom
Brand (Large): Director of Sourcing and production	Included as the participant provided a unique viewpoint on the challenges and operational dynamics specific to larger companies in the industry.	Netherlands
Brand (Small): Partner and Assistant Manager within the sourcing department of a small brand.	Included as the participant was suggested by the Technical Manager from the small brand. Those in the sourcing department are involved in supplier selection and are closer to GC implementations than other members within a brand, providing key insights into supplier decision-making and the upstream challenges of adopting GC.	India
Innovator (Colouration): Head of Operations	Included as the participant was focused on developing natural dyes, providing insights into the challenges and experiences specific to innovators working within colouration GC.	India
Innovator (Pretreatment): Director of Product Commercialization	Included as the participant was focused on developing a biobased preatreatment, providing insights into the challenges and experiences specific to innovators working within pretreatment GC.	United States
Service-based provider: Managing Director	Included as the participant engages with innovators, brands, and manufacturers using their testing and analysing services for chemistries. This gives the participant visibility into the engagement dynamics and status of GC across different actors.	India
Academic Institution: Head of The Textile Chemistry Department	Included as the participant's role often involves providing solutions to the industry through a more research and academic-based view.	India

Multi-Stakeholder Initiative: Technical Manager	Included the participant was from a collaborative platform which engages with all types of actors within the network, providing visibility on the challenges and requirements for encouraging GC adoption.	India
Consultant: Senior Technical Marketing Officer	Included as the participant offers expert advice to a range of actors within the industry, providing insights into the challenges faced and potential solutions observed from experience.	India
Regulatory Body	Regulatory bodies are included as key human actors within the analysis due to the indirect insights obtained into their role and interactions provided by other participants. However, no participants were included due to limitations in access. This may be due to strict protocols for engaging with external research projects.	N/A
Consumer	Consumers are included as key human actors within the analysis. However, due to time constraints the decision was made to prioritise additional players from other actor types where more insights were needed. Whereas for consumers, the insights drawn from other participants did not reveal any conflicting perceptions.	N/A

Table 5: Sample of interview participants

Table provides an overview of the sample of the participants for each human actor, along with reason for inclusion. Participants' identities remain undisclosed to maintain confidentiality.

4.4 Data analysis

The NVivo software was used to manually transcribe and code the interviews. Manual coding was found to be the most suitable method due to the limited sample size. This allowed for a thorough analysis and interpretation of the data, guaranteeing that the participants' responses were given greater attention (Rahman et al., 2020). A thematic method was used in the analysis combining inductive and deductive reasoning. This approach is generally used in social sciences and other fields where understanding the underlying meanings, interpretations, and experiences of actors is critical.

To answer sub-question 2, the data was analysed deductively and categorised according to the four criteria of the DOI theory: relative advantage, compatibility, complexity, and trialability. This provided specific insights on the characteristics needed to evoke actors' interest and support towards GC adoption. For example, an Indian manufacturer indicated they *"try to figure out if there's something new in the market which can be procured at a better price"*. This code was categorised under 'Relative advantage' within the sub-group of 'Price advantage'. Similar codes that expressed a preference for a price advantage were also categorised under this theme and sub-group.

As little is known about the the phenomenon of GC adoption, the remaining of the analysis used a grounded theory approach that was primarily inductive. This allowed for the emergence of new themes and concepts from the rich, descriptive data that was collected from the open-ended questions. The grounded theory approach included three iterative steps of coding (Corbin & Strauss, 1990). First, in open coding, similar codes were grouped to build

categories. For example, a brand indicated *"a challenge with* regulatory bodies*, is that they pass some kind of directive, but they should be more explicit of how to support companies to move in that direction and what to do next?"*. This code was categorised into 'Lack of Guidance'. Similar codes that expressed a lack of guidance were also categorised under this category. Following that, axial coding was used to establish relationships between the categories to develop broader themes. For example, the category 'Lack of Guidance' and 'Ineffective Due Diligence' were both grouped under the general theme of 'Decision Making'. The themes developed up to this point within Nvivo are shown in **Appendix IV**.

Finally, to help better address sub-question 1 and 3, and the main research question, selective coding was conducted in which these general themes were grouped together to form core categories according to relevance to the questions. This relevance also aligned with the concepts from ANT, namely, the actors' roles and interactions, barriers to GC adoption, and potential solutions. Miro was used to create boards to visualise the best way to group the themes. The link to Miro is provided in **Appendix V.** For example, for sub-question 1 which examined the roles and influence of each actor, the most relevant codes were grouped under each actor type and then the perceived role and influence was interpreted by the researcher. For example, the code "*brands like Nike, Adidas, Lulu, us, these bigger powerhouses, are the ones that can change industry perception and change the landscape of what is considered acceptable*", was grouped under the category 'Brands'. It was noted that large-scale brands wield significant influence due to their market share and purchasing power. The influence of this is their actions have the potential to impact the industry by setting an example and raising awareness of the benefits of GC adoption. For sub-question 3, which focused on identifying barriers, the themes developed four barrier themes; business case, operations, industry norms, and governance. For example, the code " *There is not a lot of drive towards cleaning up the supply chains domestically*" was grouped under 'Resistance to change' which was placed under the barrier 'Industry norms'. Finally, to aid in answering the main research question, the most relevant codes were grouped into categories that represented generaal solution focus areas. For example, the code, "*government needs to bring a regulation, or provide us with some benefits on the tax side*" was grouped under 'Price strategies' which was placed under the theme 'Cost considerations'.

4.5 Research quality

Trustworthiness is an essential measure of quality in qualitative research, which is made up of four quality indicators (Bryman, 2003).

First, 'Credibility' refers to how believable the findings are (Clark et al., 2021). This was ensured through the data triangulation of FFG's internal sources and internet sources during the data collection and sampling to ensure that the actors and their examples were relevant to India's textile processing. This resulted in the sampling of participants that enabled reliable data to be drawn. For brands, this data triangulation was not possible as visibility into their supply chain was proven challenging through internet sources. However, members of the FFG team were used to verify their supply chain presence within India. Additionally, the credibility of the results was ensured by building trust with the participants in various methods. Firstly, an informed consent form had to be signed prior to participation. As shown in **Appendix VI**, the form detailed the nature, goal, outcome of the study, and emphasised confidentiality. Secondly, for the participants that were more reluctant to participate, a preview of the interview questions was provided to allow

them to prepare and feel more at ease. Due to the sensitivity of topics, such as chemical use and compliance, participant trust was necessary to ensure honest responses were given throughout the interviews.

Second, ‘Transferability’ refers to the applicability of the findings to other contexts. While the study is specific to the context of India, the methodological framework was robust as it was guided in a theoretical framework. Additionally, the approach was transparently provided throughout to allow other researchers to assess the applicability and apply the methodology to their own context. The only changes that would require being made are the identification of actors and alterations to the interview guide.

Thirdly, ‘Dependability’ refers to an auditing approach in which all phases of the research are documented. This was ensured by detailing the entire research approach and providing access to all the tools employed throughout the research. For example, the Excel Document used during the desk research, and the NVivo project and Miro boards used for the analysis are all accessible in the appendix.

Lastly, ‘Confirmability’ refers to minimising personal values or theoretical inclinations from influencing the research methods and findings. This was ensured by having a supervisor from FFG and Utrecht University review the study throughout. The supervisors identified potential weaknesses and provided constructive feedback, enabling the study to be iteratively refined. Additionally, direct quotations from the participants were provided for transparency behind the interpretations made. This ensured that the findings for each research question were rooted in the data collected rather than personal biases.

5. RESULTS

5.1 Unraveling the actors within the network

This section pertains to the sub-question '*What roles do human and non-human actors hold within India's textile processing network and how do they influence green chemistry adoption?'.* The findings directly corresponded with the concept of problematisation within ANT, focusing on defining the actors' roles within the network. Determining these roles helped distinguish the interactions within the network, which was imperative to understand their influence within the network, as well as to reveal the contribution of each actor towards the barriers of GC adoption (discussed in **Section 5.3**). Additionally, identifying the actors' roles and interactions was a crucial step in informing the development of the final OPPs, as they necessitate enrolling actors with their existing roles or leveraging existing strengths and interactions for them to actively engage in achieving the common goal of creating a network that facilitates GC adoption.

Figure 3 depicts a relationship map of the actors' roles and interactions within the network based on the perceptions from each participant. The map may not be exhaustive of all the actors involved in the real-world context, but solely of those identified via the data collection and analysis. As noted in the Section x, the actors were positioned as either key actor or supporting actors depending on the perceived influence they have on the network; The key human actors (purple) include manufacturers, brands, consumers, industry associations, regulatory bodies, and MSIs. Key non-human actors (green) include GC, legislation, RSL, certification, machinery, and trials. Supporting human actors (yellow) include innovators, industry consultants, academic institutions, and SBPs. Supporting non-human actors (blue) includes LCAs, best practice guidelines (BPGs), and fiscal incentives.

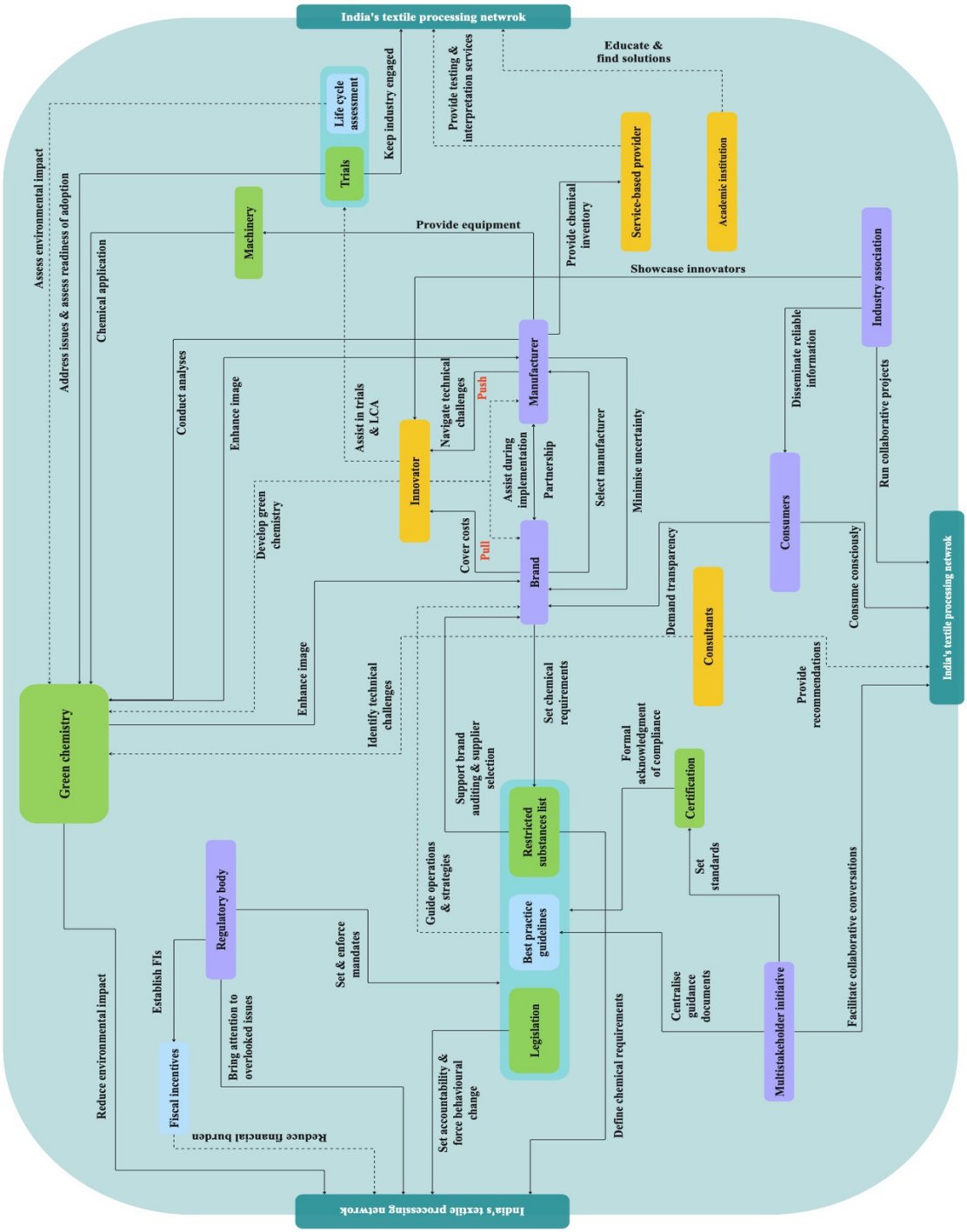

Figure 3: Actor-network relationship map

The map depicts the actors and their respective roles. The interactions are depicted by the arrows, with those pointing towards 'India's Textile Processing Network', signifying that the role is directed towards more than one actor in the network. The actors include key human actors (purple), supporting human actors (orange), key non-human actors (green), and supporting non-human actors (blue). The bold arrows are to demonstrate that more influence is exerted by the roles than those with the dotted lines. The link to the figure can also be found in ***Appendix V.***

5.1.2 Key human actors

Brands. A brand is a company which sells garments within the textile industry. Brands' key roles emerged as covering costs and setting chemical requirements, thereby holding a significant power dynamic over the other actors within the network. The power exerted from brands, was especially identified from the 'powerhouses' who yield the ability to shape the network's perception. As well as the 'champions' within brands that are more actively engaged in driving the change within a brand. Therefore, brands were positioned as key human actors within the network.

There was a consensus that brands are responsible for covering the costs. An interviewee from an industry association highlighted, "*brands will enable or pull the adoption given that premium pricing will only be invested in if the brands are willing to adopt*." This perception of the need of financial investments from brands for successful adoption highlighted brands' purchasing power in the network. Additionally, an interviewee from a large brand referenced Nike, Adidas, and Patagonia as lead influencers claiming its "*these bigger powerhouses, which are the ones that can change industry perception and change the landscape of what is considered acceptable due to having the capacity and resources to demonstrate the potential of sustainable products*." The reference to "*capacity and resources*" confirmed the power yielded from their purchasing power, enabling them to shape the network's perception and redefine what is considered acceptable. This power dynamic reflects what is often referenced as 'brand pull-through', where brand efforts are necessary to inspire other actors to follow suit.

An interviewee from a small brand noted "*they set chemical requirements for the whole business, for all product categories at a policy level and then publish those to the supply chain*." This authority imparts significant influence on manufacturers, encouraging them to meet their requirements to secure business partnerships. An interviewee from a SBP highlighted that that MRSLs developed by brands allows them to "*instruct suppliers that they must buy chemicals which conform to ZDHC MRSL 1, 2, or 3 level.*" The use of the word "*instructs"* underscored the power dynamic imposed by brands.

Within the brand actor group, it was revealed that brand influence is significantly dependent on the "champions". An interviewee from an industry association revealed, "*Whether big or small, it really depends on the champions within the brand who are pushing for it. These champions are more inclined to invest in educating their supply chain partners and strive to provide technical assistance and training to facilitate their transition to GC practices*". This revealed a perception that brands' success in exerting influence is highly dependent on these "champions" as they are more strategically inclined to actively engage with other actors, provide support, and advocate for GC.

Manufacturers. A manufacturer is a company transforms raw materials into a finished garment via processing in which chemicals are applied and garment construction. Manufacturers' key roles within the textile processing network emerged as conducting thorough chemical analyses, navigating technical challenges, minimising brand uncertainty, and providing machinery for chemical applications. This makes them crucial human actors within network, especially in their partnership with brands. Therefore, positioning them as key human actors.

The significance of robust partnerships between brands and manufacturers was expressed throughout all the interviews. An interviewee from a large brand noted, "*brands often dictate which chemicals they prefer not to work*

with, the feasibility of adopting certain chemicals ultimately depends on the manufacturers." This revealed that while brand preferences wield a significant influence, manufacturers' perspectives play a critical role in determining the ultimate success of adoption. Similarly, an innovator emphasised this dynamic by expressing, "*If a mid-size brand works with a leading supplier, the supplier may take the lead in influencing decisions due to the brand's dependency on them as the they increasingly educate the brand on sustainable practices, thus becoming more influential*". This illustrated the dynamic nature of their partnerships, in which the volume of their business can help give precedence, and as trust grows, this can further strengthen into a more mutually dependent relationship.

A consultant highlighted that it is uncommon for a manufacturer to "*jump directly and get excited. They will say wait, let me do all the analyses first and then put it into the system to determine where it will and will not work.*" This inclination to conduct analyses revealed that they are perceived as trusted partners capable of providing reliable opinions on a chemical's viability. As highlighted by an interviewee from a brand this is essential to minimise uncertainties and "*provide clarity as sometimes it's challenging for us to trace beyond what our brand is doing...we need to know if there are any differences or if something is new to them, so we can consider it in our processes. It's a regular catch-up with them to understand the smooth transition toward manufacturing processes that incorporate greener chemical alternatives*." This perception from brands underscored the perceived significance of regular interactions with manufacturers, contributing to the brand's decision-making process.

An interviewee from an industry association acknowledged that manufacturers are positioned "*to scale and navigate some of these problems.*" Similarly, an innovator highlighted their effectiveness in implementing new technology due to being "*equipped to implement new technology effectively.*" These abilities underscored the perceived adeptness in navigating technical challenges and their critical role in providing the machinery necessary for chemical applications.

Consumers. Consumers' role emerged as pivotal for demanding transparency and consuming consciously to influence the market. An interviewee from MSI noted, "*The textile industry is publicly driven. If the public demands, the brands will also be forced towards that"*. The reference to a "*publicly driven*" industry underscores the influence impacted by consumers in driving the direction of the industry. Therefore, positioning consumers as key human actors. The role of consumers is twofold. First, as indicated by an interviewee from a brand, "*consumers are becoming more aware and we see that they want to know more. There's a lot of activisms in the upcoming generation, and they want us to say something about everything, whether they understand it or not*". This reveals that their role in demanding transparency has placed greater scrutiny on brands, encouraging them to reconsider their products and operations for fear of losing their customer base. Second, consumers can actively promote conscious consumption by opting for brands that align with their values and boycotting those that do not meet standards. This shift in consumer preferences has also forced the industry to take accountability and reconsider chemical use, reinforcing the perception of the industry being "*publicly driven.*"

Industry associations. An industry association is an organisation that helps advance a specific industry by supporting different stakeholders and individuals. Within the textile processing network, industry associations' role emerged as disseminating reliable information, initiating collaborative projects, and showcasing innovators. Thus, positioning

industry associations as a key human actor. An example of an industry association is FFG which is focused on the textile industry. As outlined by an interviewee from a brand, "*a lot of consumers come to FFG and similar organisation to search for information because they want to know if what a brand is telling them is authentic and true. A brand will always tell a story, but an independent organisation will hopefully be telling the truth of the matter as they are not necessarily brand affiliated*". The reference to "*telling the truth"* revealed that Industry associations, such as FFG, are perceived as trusted sources of credible information, bridging the gap between brand narratives and consumer expectations. In turn, this can be valuable by empowering consumers with information to make informed buying decisions, directly influencing consumer behaviour (refer to the section on consumers).

By leveraging their status as trusted sources, Industry associations initiate collaborative projects that help bridge the knowledge gap surrounding the impact of chemicals, whether by conducting trials or spreading knowledge. An example of this is the Dyestuff Library Project initiated by the FFG, "*which looks at dyes and how they compare in terms of performance metrics, impact and scalability*." These types of projects involve leveraging their extensive network assists brands and manufacturers in scouting GCs, while also helping innovators to find the "*right supplier and partner mix in the region*". Thus, facilitating the seamless integration of GC into supply chains by navigating the complex dynamics within the network.

Multi-stakeholder Initiatives. A multi-stakeholder initiative is a group of different stakeholders brought together with the aim of solving social, environmental, or economic issues across different industries. As noted by an interviewee from an MSIs they are responsible "for understanding industry needs". Thus, positioning them as key human actors within the network. Within the textile processing network MSIs' role emerged as developing chemical standards for certifications, facilitating collaborative conversations, and centralising guidance documents. An interviewee from a small brand highlighted MSIs such as ZDHC "*create lists of substances beyond the law, that they want to lobby restrictions around use. ZDHC also provides alternative chemistry, from which the innovation can be spurned*". This acknowledgment, especially from a brand, demonstrated that brands are not passive observers, but actively value and rely on responding to the directions set by MSIs. Additionally, an interviewee from a brand highlighted that MSIs "*become invaluable, as they facilitate collaborative conversations*" within the network. Via these conversations, it was revealed that MSIs serve to "*understand industry needs*", as well as drive alignment and ensure a shared understanding of the rationale behind the standards they establish. For instance, one of these needs an interviewee from an MSI uncovered was the current nature of information and resources within the industry, often being fragmented. Recognising this issue, the interviewee revealed one of the responsibilities included gathering critical tools and materials in accessible formats, such as "*guide documents, where everything is collated in one document.*" The centralisation of this information can assist in driving GC adoption, as it helps streamline processes by empowering actors with the ability to make more informed decision-making.

Regulatory bodies. A regulatory body is an organisation made up of a group of individuals which oversee industry practices and regulate the standards in which an industry operates. Thus, positioning them as a key human actor. Within the textile processing network, regulatory bodies' role emerged as a key driver in behavioral change through enforcing mandates (such as legislation, BPG, and RSL), establishing fiscal incentives, and bringing attention to

overlooked issues. An innovator emphasised *"the governments have to bring in regulations to force people to change and that's when change will actually happen*". This stressed the unique position of regulatory bodies in enforcing regulations that promote significant changes in behavior. This behavioral change was exemplified by the growing awareness surrounding the use of PET bottles within the industry. An interviewee from a large brand noted, "*If the EU didn't outlaw the use of PET bottles as part of recycled polyester going forward, we would just continue to use it, and most of us blind as to where it comes from".* The reference to previously being "*blind*" highlighted the way in which regulatory actions place emphasis on issues that were previously overlooked, forcing the industry to reevaluate their choices. Lastly, an innovator stressed regulatory bodies "*need to bring a regulation or provide us with some benefits on the tax side*". This underscored the power of regulatory bodies towards behavioral change through the provision of FIs, such as tax-related benefits, to better facilitate adoption.

Nonetheless, the interviews revealed a perceived disconnect between the regulatory bodies and the rest of the network, indicating their interactions within other actors is somewhat limited. For instance, an interviewee from a brand said, "*I think we have a better ear on the ground than* regulatory bodies *do"*. This sentiment was also echoed by the difficulty in recruiting a participant from a regulatory body for the interviews, and most of the participants not being able to provide a contact. While possibly necessary for regulatory bodies to maintain an authoritative position, it also raises questions about the effectiveness of their role due to the evident lack of GC adoption.

5.1.3 Supporting human actors

Innovators. An innovator is a human actor which develops innovations – in the context of this study develops GCs. Innovators emerged as supporting human actors due to the consensus that they have *"little influence on the supply chain".* A consultant noted they often have "'*limited bandwidth or knowledge*', indicating that their specialised knowledge is perceived as too narrow focused. This contrasts with key human-actors perceived to have more comprehensive knowledge owing to their wider experience across textile processing and industry operations. Nonetheless, innovators' role emerged as invaluable due to their responsibility in developing GCs aimed at reducing the environmental impact of the industry. Additionally, they also serve in assisting throughout implementations, trials, and LCAs by *"helping transfer the recipe, making them understand the price and providing day-to-day R&D that is required for continuous improvement of the process".*

A noteworthy dynamic is the strategic approach employed by innovators, often referred to as a 'push-pull approach,' to leverage the influence of brands and manufacturers. This strategy, illustrated by the red arrows in **Figure 3**, involves a push approach where innovators directly interact with manufacturers to establish trust and educate them on the economic and environmental benefits of their GCs. This is perceived to make manufacturers more inclined to navigate technical challenges and educate the brands on the feasibility of the GC. While with the pull approach, innovators collaborate with brands through "*discussions that empower brands to advocate for our technology, acting as a catalyst for change within the supply chain".* By providing a sense of empowerment to the brands, they become more inclined to cover the cost, enabling the brand pull-through required for adoption. This dual approach exemplifies the dynamic interaction required between innovators, brands, and manufacturers to facilitate the adoption of GC.

Industry consultants. Consultants emerged as supporting human actors as they were not mentioned by the participants. However, numerous consultants were listed within FFG's internal sources during the desk research. Additionally, the researcher positioned at FFG has worked closely with various consultants alongside other human actors identified within the study throughout trials and projects based in India. This was an indication that they provide invaluable contributions towards facilitating the adoption of GCs. The lack of their mention by the participants suggests that their level of input varies on a case-to-case basis depending on the GC and the barrier encountered.

The consultant interviewed described their role as providing recommendations and identifying challenges. Additionally, the consultant detailed their interactions with manufacturers, stating, '*We come in and visit manufacturing facilities, identify the reasons, educate, and communicate with the team. Communication is a crucial aspect. We strive to understand why things are not working and then act.*' This hands-on approach underscored consultants' ability in establishing an open space for open communication with their customers, facilitating the exchange of recommendations. Additionally, their direct experience gained within facilities places them in the position to identify challenges and provide tailored recommendations, thus fostering confidence in their contributions.

Academic Institutions. Academic institutions emerged as supporting human actors as they were only mentioned by two participants. An interviewee from an Academic institution noted they "*incorporate topics into the syllabus related to environmental management, utility conservation, waste management, sustainability, and circularity*". This highlighted their role in imparting education within the textile processing network by equipping future generations with the practical knowledge and problem-solving skills applicable to the industry. Additionally, an innovator detailed their interactions with AI for *"helping find new colours and support on how to grow raw materials*". This revealed their role in finding solutions owing to the extensive research they carry out.

Service-based providers. A SBP is a third-party organisation that providers various types of services across different industries. Within the textile processing network, SBPs emerged as supporting human actors as an interviewee from a SBP explicitly stated "*we do not have much influence on adoption in the world and cannot provide direct support as that would be a conflict of interest"*. This statement underscored the need for SBPs to be impartial for the testing and interpretation services they provide to the network, making them critical intermediaries for maintaining integrity within the network. These services SBPs provide include receiving chemical inventories and screening them to confirm that chemicals meet industry standards such as the ZDHC MRSL and The Global Organic Textile Standard. An interviewee from a brand noted they engage with SBPs since they "*have an advanced system for managing chemical inventory provided by suppliers*". This highlighted the perceived effectiveness of their capabilities, and the value they bring to brands in maintaining oversight over their supplier's use of chemicals, enabling them to make informed decisions during supplier selection.

5.1.4 Key non-human actors

Green chemistry. GC is defined as lower impact chemicals, and were positioned as key non-human actors due to their ability to significantly influence the actors' within the network in various ways. For example, the GC can influence the machinery used, as in order to accommodate the unique requirements of GC, existing machinery may require

adjustments or even new replacements. Moreover, as manufacturers benefit from cost savings stemming from the reduced impact of GCs, this can change their current operations or the investment strategies. Additionally, as GCs increasingly prove to be viable alternatives to traditional chemicals, legislation can evolve to favour them. Within the textile processing network, GCs' role emerged primarily as means to reduce environmental impact, and a means to strategically enhance image within the network.

The participants all acknowledged the GCs role in reducing environmental impact by exemplifying various environmental benefits. For instance, an interviewee from an AI listed their role in "conserving the environment, environmental protection, solid waste reduction, liquid waste management, and mitigating gaseous emissions." Beyond environmental considerations, GC was also perceived to have practical applications. For example, an interviewee from a MSI detailed their "greater flexibility, lower maintenance, and better control over the production process...When you do the calculations, you'll find that GC often comes out as the more economical choice."

Beyond environmental considerations, the interviews revealed GCs can serve to enhance their image. Thus, driving access to new business relationships or markets. An interviewee from an industry association noted that brands are more willing to adopt GCs if they see a "*storyline and narrative, whereas suppliers see it as an extra value proposition for when they sell to their clients*". This interest in enhancing their image was echoed by various interviewees, with an interviewee from an academic institution observing that GC projects conducted with industry actors most often spur from the request of exploring "anything to offer... to differentiate themselves from others". This desire for differentiation underscores a broader goal of enhancing reputation and image, rather than solely focusing on impact savings. The importance of GC adoption for brand image was also underscored in the context of regulatory compliance. An interviewee from a brand stated, "We *stay updated on UK regulations and government requirements, and we aim to enhance our brand image through our supply chain, which is supportive in this regard*". The reference to the supply chain being "supporting" revealed that this belief is prevalent across the supply chain.

Furthermore, the interviews revealed the adaptable nature of GC. An interviewee from a manufacturer noted, "*green chemicals are the ones which are compliant. There's no standard definition for green chemicals"*. The use of the word "*compliant*" suggests that definition evolves in response to regulatory changes, reflecting the pressure manufacturers face in meetings the requirements set by brands. While an interviewee from a SBP noted, "*my definition is not set because GC per se has many different meanings based on methodology*." The reference to variability in definitions based on the methodology, suggests that the definition evolves in response to technological advancements. While this adaptability presents a complex dynamic, it promises that adjustment can be made to the network to better facilitate the adoption of GC.

Legislation. Legislations are a set of laws which dictate how an individual or organisation behave. Thus, positioning them a key non-human actor. Legislations' role emerged as forcing behavioural change and holding the network accountable. An innovator emphasised "*regulations force people to change and that's when change will actually happen*". This sentiment was echoed by all the participants and its influence exemplified by their experience with REACH. An interviewee from a small brand emphasised that REACH was *"the most powerful force in changing the landscape of chemistry usage*". This is due to requiring actors to assess whether their current chemical management

systems require modifications, forcing behavioural changes towards enhancing their current practices. An additional example was the impact of the legislation around wastewater pollution in India. An interviewee from an industry association indicated that the management of wastewater pollution "*radically changed*" with the implementation of wastewater cleaning Technologies and wastewater treatment plants within the region. The reference to quick and radical change revealed the perceived efficiency imparted by legislation on behavioural change. Moreover, an interviewee from a large brand expressed the role legislation plays in keeping the brands "*honest*", since "*there are some brands that are going to be very diligent in understanding where their recycled plastic is coming from and there's brands who will close an eye.*" The reference to honesty revealed the influence legislation has on holding actors accountable by shifting guidelines from advisory to obligatory. This acts as a safeguard to ensure that brands prioritise sustainability due to the acknowledgement that failure to adhere can lead to consequences

Restricted Substance Lists. RSLs' role emerged as defining lists of restricted or prohibited chemicals and supporting brand auditing and supplier selection. RSL includes Product Restricted Substance Lists (PRSL) outlining chemicals restricted at the product level, and Manufacturing Restricted Substances Lists (MRSL) outlining chemicals during the manufacturing process. Eight out of the eleven participants, excluding the two innovators and the interviewee from the acadmic institutions, mentioned the influence of RSL or their use within current operations. This signalled their significance wihtin the network, positioning them as key non-human actors. An interviewee from a manufacturer highlighted that these lists provide better control and monitoring of chemical usage within their supply chain, since brands rely on RSL during auditing, and both product and supplier selection. Moreover, an interviewee from a brand observed that "*before, the requirements were singular and solely focused on a legal framework, but now we have moved to PRSLs, which have stretched into aspirational standards".* This shift to aspirational standards revealed that RSL influences higher accountability standards, encouraging brands to proactively address chemical challenges and adopt GC.

Certifications. A certification is a standard that outlines specific requirements expected to be met. Within textile processing network Certifications' role emerged as serving as a formal acknowledgment of adherence to industry requirements, thereby influence the decision-making process for manufacturers and brands on which chemicals to adopt. Thus, positioning them as key non-human actors within the network.

As exemplified by an interviewee from a brand, *"Once a certification is uploaded, it provides visibility into all their processes, not only in* garment manufacturing but also in the sourcing of raw materials". The reference to providing visibility revealed that certifications provide the assurance that certain requirements are being met. This showcases a commitment to certain requirements, and so are viewed as an asset to gain access to new markets.

Three certifications emerged throughout the interviews. First, ZDHC was recognised as the *"leading certification"* by various participants, with an interviewee from a SBP indicating that it is *"the most popular in India". Second, a*n interviewee from a brand mentioned they *"work with mills that are BLUESIGN certified. Although, there is a lot of debate about whether that is the right certification."* The mention of specifically working with Bluesign certificated mills, highlights the role of certification in influencing sourcing strategies. However, debates about its

effectiveness suggests that while the certification are perceived as valuable, they do not always align with brand expectations. Third, an interviewee from a brand noted *OEKO-TEX,* however acknowledged that *"it is much more popular than we were aware within our supply chain. We had the working assumption that most of the legal compliance was predominantly testing-based. And actually, it turned out to be more biased towards OEKO-TEX, which is a good thing because it drives value."* The brand's initial underestimation of OEKO-TEX's prevalence suggests that certifications have a deeper penetration and acceptance in the industry than some brands might assume. This reveals that certification have become integral within the network, signalling a collective move towards meeting environmental requirements.

Trials. A trial is a method in which a GC can be tested to showcase the outcome of the use of a chemical. An interviewee from an academic institution, "*lab and pilot trials are a must. You need to test what you get in a small beaker on a larger scale, and then only then can you take it to the shop floor or production*". This explictly highlights the use of trials before any GC is adopted. Thus, positioning trials a key non-human actor. Within the textile processing network, trials' role emerged as a means to identify and address issues, assess the readiness of adoption, and keep the industry engaged.

An innovation emphasised, "*conducting trials is indispensable. It offers first-hand insights into the real-life manufacturing challenges. While addressing one problem, we often find ourselves solving other challenges as well*". This underscored the significance of conducting trials to identify the unique issues that arise when scaling innovations and addressing them. As emphasised by an interviewee from a SBP this paves the way towards providing "*partners assurance that the chemistry can really be taken from the lab scale all the way to industrial scale"*.

From the interviews a clear discrepancy of the value of each trial was indicated. A lab trial is "*a proof of concept necessary to put the innovations on the brand and supply chain partners radars. It also shows where investments should start moving"*. A pilot scale gives more tangible results as "*when you touch, feel and measure stuff close to a commercial level you can tangibly see something coming to market*". Lastly, industrial scale trails "*are essential to see that you can work with the technology*". These trials are usually carried out sequentially, signaling an advancement towards readiness for adoption. Nonetheless, an innovator noted that trials serve as a tool to "*keep the industry engaged.*" While this may refer to gradual improvements in GCs by navigating technical issues, the reference to sustaining interest, combined with the evident lack of widespread GC adoption, suggests that trials may often be used strategically to maintain engagement and investment from various actors rather than as a genuine means to advance the viability of GCs. This raises questions about the effectiveness of trials in truly facilitating the adoption of GC, as some actors perceive them more as a performative tool.

Machinery. As noted in **Section 1.1**, the relationship between machinery and chemistry is interdependent, with machinery being essential for the application of a chemical. Thus, positioning machinery as a key non-human actor within the network. Due to this fundamental interconnectedness between the two the decision was made to intentionally narrow the focus just to chemistry within the interviews to ensure that insights on the unique considerations of GC were not lost.

Despite this, the significance of machinery on the influence of GC adoption was underscored, specifically in discussions around compatibility in **Section 5.2.2.** There was a clear consensus that compatibility was as a key characteristic for evoking actors' interest and support in GC adoption, with the extent of it being the compatibility to existing machinery. An interviewee from an industry association emphasised the "*usability of dyestuff in existing machinery, so they don't have to change the infrastructure*", an interviewee from a manufacturer noted "*it's about substituting chemicals within the same machinery*", and an innovator expressed that the benefit of their GC was "*its versatility and applicability across diverse machine types, irrespective of age or technology*." These statements both underscored the influence machinery can have on the decision-making around GC adoption.

5.1.5 Supporting non-human actors

Life Cycle Assessments. LCAs role emerged as a tool to assess the environmental impact of a product. These assessments are often used as a communication tool to customers. However, an innovator stated, *"brands acknowledge that LCAs aren't a definitive metric for assessing technology. However, they still see value in them for branding purposes"*. This revealed a perceived limitation in their ability to capture the full environmental impact of an innovation, especially during the earlier stages of GC development. Additionally, there was a lack-of their mention among the participants, indicating they do not hold significant influence in the adoption of GC. Thus positioning them as supporting non-human actors.

Best Practice Guidelines. BPGs were not initially mapped as an actor during the desk research, but emerged as a non-human actor throughout the interviews. The mention of BPGs was minimal, thus, positioning them as supporting non-human actors. However, through the two examples provided by the participants, their role emerged as tools to guide brands with their operations with their sustainability strategies. An interviewee from an MSI highlighted the use of the "*Responsible Solvent Approach Guide, which discusses solvent substitution studies"*. The clear emphasis on solvent replacement uncovers a larger commitment of BPG to encourage the use of alternative chemistries with lower environmental impact. Another example provided by an interviewee from a brand was a "*Publicly Available Specifications documents, which provides guidance on best practices including ensuring the safety of products on the market.*" The interviewee also detailed that it "*prompted us to change our approach to working with suppliers. We are now engaging with them in a more rigorous manner, which involves conducting thorough screenings and risk assessments before onboarding any new suppliers"*.

Fiscal Incentives. Fiscal incentives were not initially mapped as an actor during the desk research but emerged as a non-human actor throughout the interviews. The role of fiscal incentives emerged as a means to reduce the financial burden associated to GC. An interviewee from a brand pointed out that "*Brands are incentivised by profitability and market share – they are very financially driven...it could be in the form of a subsidy. If you implement this new thing, you can apply for this subsidy."* Similarly, a manufacturer expressed, "*The government needs to bring a regulation or provide us with some benefits on the tax side"*. Both these statements urged regulatory bodies to establish fiscal incentives to encourage further investments in GCs, highlighting their influence in GC adoption. Nonetheless, fiscal

incentives were only mentioned by manufacturers and brands, both of which typically incur the highest costs in GC adoption. This not only supports their role in reducing the financial burden of GC, but also reflected their limited direct impact on the broader network. Thus, positioning fiscal incentives supporting non-human actors.

5.2 Key characteristics for Green Chemistry adoption

This section pertains to the first sub-question: '*What key characteristics are required to evoke actors' interest and support in Green Chemistry adoption?*'. The findings were drawn following the DOI criterion, while contributing to the understanding of the movement of Interessement within ANT. Determining these characteristics was a crucial step in informing the development of the final OPPs, as it identified which characteristics were required to evoke actors' interest and support to actively engage in achieving the common goal of creating a network that facilitates GC adoption.

Figure 4 depicts the characteristics identified within each criterion of DOI theory, along with the underlying motivations of why the characteristic is required to evoke actors' interest and support towards GC adoption.

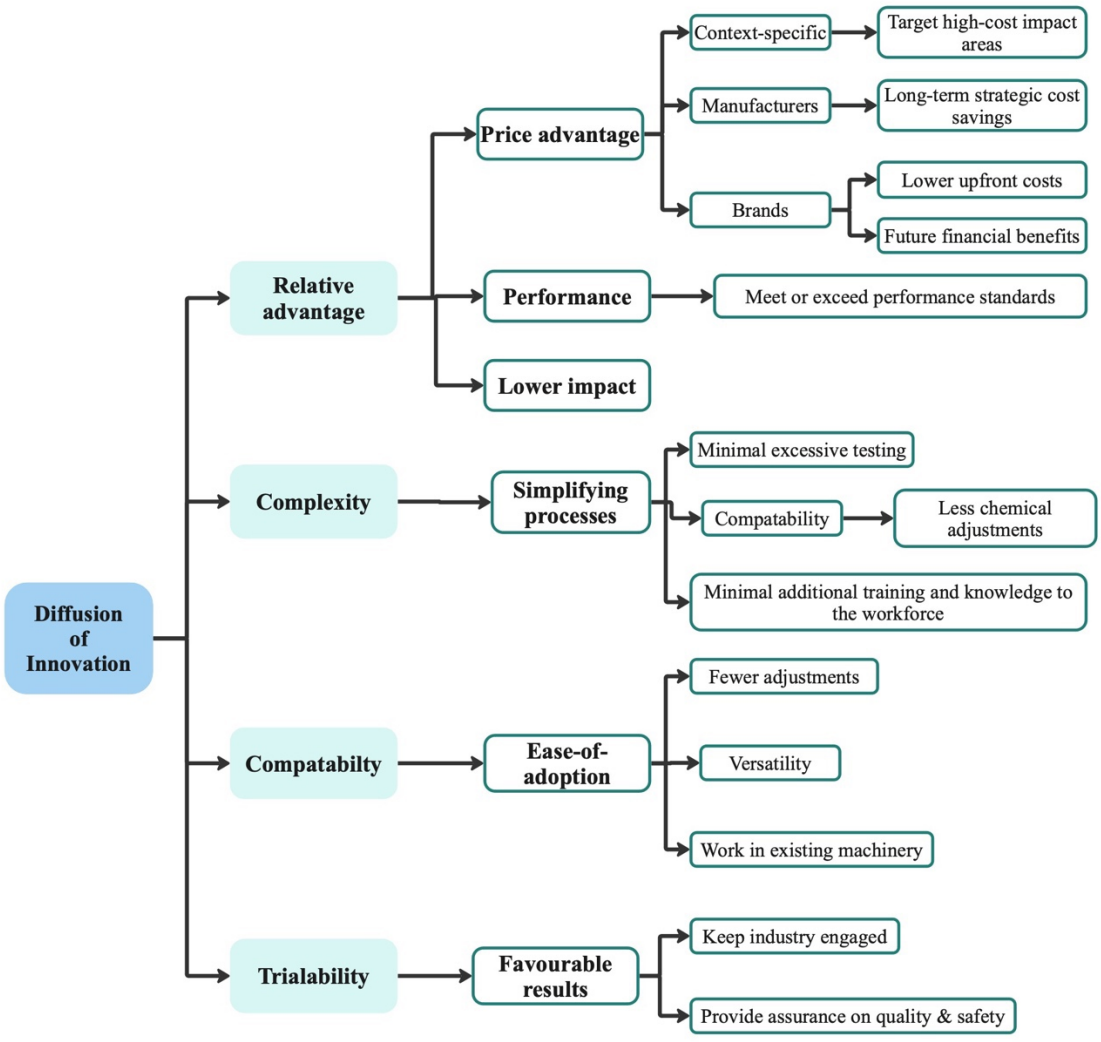

Figure 4: Key characteristics evoking actors' interest and support

Figure depicts the key characteristics perceived to evoke actors' interest and support towards green chemistry adoption identified through the diffusion of innovation theory. The link to the figure can also be found in ***Appendix V.***

For **'Relative advantage';** a price advantage emerged as high interest, with manufacturers prioritising long-term cost savings, while brands motivated either by low up-front costs or future financial benefits. Context-specific price advantages which focus on addresses high-cost impact areas also emerged as a significant area interest. Additionally, achieving or exceeding industry performance standards emerged as an essential characteristic to perceive a relative advantage. For **'Compatibility,** ease-of-adoption emerged as a key interest, achievable by the chemical's versatility, compatibility with existing machinery, and the need for minimal adjustments. For '**Complexity'**, the processes were perceived as simpler if required fewer recipe adjustments, minimal additional training, and fewer trials. For '**Trialability'**, the ability to obtain favourable results emerged as high interest to provide assurance of the GC's viability.

5.2.1 Relative advantage

Impact saving. As defined in the study, GC aims to reduce environmental impact. This role was recognized by all participants, who highlighted a range of environmental benefits provided by GC, as detailed in **Section 5.1.4**. With increasing awareness of these advantages and a greater urgency to reduce the impact of textile processing, this characteristic has become increasingly valued as a significant advantage of GC. For instance, an interviewee from an academic institution noted, "*any technology that helps reduce water and chemistry use is the big push right now*". This statement revealed that there is the perception that there is a growing trend towards adopting GC if impact savings are evident. This sentiment was consistently emphasised by all the participants when asked about the value of GC. An interviewee from a manufacturing firm pointed out, "*I don't think I have to say anything about the green chemistry's added value from the perspective of the environment. I think, that is self-explanatory*". The reference to GC's added value as "*self-explanatory*" captures the broad consensus among the actors that the relative advantage of impact savings is both clear and widely acknowledged.

Price advantage. Obtaining a price advantage emerged as a critical characteristic to evoke the interest and support from manufacturers and brands since they both typically cover the costs of GC. An interviewee from a manufacturer explicitly stated actors typically *"try to figure out if there's something new in the market which can be procured at a better price. Everybody looks for a price advantage"*. However, the participants highlighted differing motivations for a price advantage.

Manufacturers employ a more strategic approach via assessing the long-term cost savings achieved by addressing high impact areas that incur high costs within their operations through resource optimization or improvements within their operational efficiency improvement. This was exemplified by an interviewee from a manufacturer highlighting their "*transition from high to medium exhaust dyes"*, due to the financial gains from savings both water and energy. On the other hand, for brands there were conflicting views on their motivations. Some participants perceived brands' interest to be centered on lower up-front costs, with an innovator observing, "*they want to buy the most they can for cheap*". This focus reflects their role in having to *absorb the higher costs" as noted by an i*nterviewee from a manufacturer in **Section 5.1.2.** While other participants and brands expressed the opinion that some brands recognise the financial benefits that can be obtained in the future, as highlighted by an interviewee from a brand, "*at one point we'll get to this critical mass, and it will no longer be as expensive as it is today*". The contrasting views

behind brand's motivation for a price advantage underscore the significance of understanding these motivations on a case-by-case basis to better adjust investment proposals and communication tactics which support their objective.

The interview also underscored the importance of developing GC that are context-specific and target high-cost impact areas, exemplified by the interest shown by Indian facilities on GCs which contribute to salt reduction or recovery. An industry consultant emphasised, "*if you use a process or a chemical where you don't need salt for the same type of colouration, then the amount of salt which needs to be recovered will be reduced and this will automatically reduce the amount of energy and then there will be cost savings*." The reference to "*cost savings*" highlights the perception that GCs which lower operational costs are of higher interest, thereby linking the perceived price advantage to the successful adoption of GCs.

Performance. Performance emerged as a critical characteristic for evoking actors' interest and support. This was explicitly underscored by the consensus that performance is a major barrier in GC adoption by all the participants. For example, an interviewee from an academic institution emphasised, "final performance needs to at least match with synthetic colours that are currently used", while an interviewee from a brand noted, "there is reluctance in India to adopt GC because...there is a performance element that is reduced right". Additionally, it was observed that even when discussing the benefits of their GC, and innovator noted it "*not only reducing CO2 emissions and water usage, but also enhances the quality of the cotton fabric by preserving its natural properties."* Although the emphasis on performance was less explicit, the innovator still underscored the importance of maintaining the end product's quality and integrity to attract customers, suggesting that impact savings does not take precedence over achieving performance parity with existing chemicals.

5.2.2 Compatibility

Ease-of-adoption. There was a clear consensus amongst all the participants that compatibility was a key characteristic to evoke actors' interest and support towards a GC. This consensus stemmed from the fact that when GC is compatible with existing machinery, it is perceived to significantly enhance the ease of adoption. Chemistry is commonly seen as a 'drop-in solution' due to its ability to be readily replaced within existing machinery. In contrast to machinery which involves physical equipment to be replaced, often requiring high financial investments and the workforce trained. Therefore, compatibility to chemistry refers to how easily traditional chemicals can be substituted with minimal adjustments to current processes and recipe. When participants were asked about the value of GC or what criteria they consider important in adopting such solutions, all responses highlighted the importance of this trait. A consultant explicitly noted, "*it needs to not have any incompatibility issues. Any technology that is more compatibile, is more likely to be adopted*", an interviewee from an industry association emphasised the "*usability of dyestuff in existing machinery, so they don't have to change the infrastructure*", an interviewee from a manufacturer stated "*it's about substituting chemicals within the same machinery*", and an innovator expressed that the benefit of their GC was "*its versatility and applicability across diverse machine types, irrespective of age or technology*."

5.2.3 Complexity

Simplifying processes. Simplifying processes emerged as a key characteristic to reduce the perceived complexity and evoke actors' interest and support. There was a consensus that complexity was highly dependent on the additional training and knowledge required within the workforce. Moreover, complexity was also dependent on the extent of the chemical compatibility, the extensiveness of trials and testing. An innovator explicitly stated "*people are often resistant to change, even for minor adjustments. This resistance stems from a need for simplicity in processes, especially since many operators may not be extensively trained*". This direcly underscored the need for simpliyfing processes by minimal additional traning. Additionaly, an interviewee from a brand revealed, "*not every brand has a talent pool or employee base big enough to dedicate the time and energy and brainpower to this type of thing. And it's super complex, so it would be great to see brands having access to organisations that can help them at nominal fees.*" The mention of providing assistance at nominal fees directly supports the interest in simplifying processes through a practical approaches, where external guidance can evoke interest and support due to reducing the burden of requiring additional training and knoweldge within the current workforce. In terms of chemical compatability, an interviewee from a manufacturer "*each setup has unique considerations*." This referred to the uniqueness in the recipes required for each chemistry, such as pH, temperature, and additional auxiliaries, where determining the most appropriate parameters can often be perceived as complex. Therefore, the fewer changes required to adopt a new chemistry, the less complex the transition is perceived to be. Finally, a consultant expressed the reluctance towards "extensive trials and testing", and further detailed there is "a *gap between the innovator's community and the user community. The user community wants to use Plug and Play. They don't want to do experiments. They do not want to go through change."* While trials are unavoidable due to their value in assessing the viability of the GC, this highlighted the need to minimise excessive testing to reduce perceived complexity.

5.2.4 Trialability

Favourable results. The extent to which a GC can be tested through trials emerged as a key characteristic significantly influencing actors' interest and support. This capability was underscored as essential, with an innovator emphasising, "conducting trials is indispensable," and an interviewee from an academic instution confirming, "lab and pilot trials are a must". As outlined in **Section 5.1.4**, trials serve crucial roles in identifying and addressing technical issues, assessing the readiness of adoption, and keeping the industry engaged – each signifincant drivers towards GC adoption. The significant value of testing GCs was further highlighted by an interviewee from a service-based provider who noted trials value as "enourmous" and that the lack-of trials for innovators leads a lack recognition. Supporting this claim a consultant urged brands to take proactive steps, suggesting they "should have a little more courage to encourage the adoption of these innovations by making capsules and piloting them, so they can scale up." This call to action further emphasises the signifincance of testing GCs to facilitate their adoption.

5.3 The barriers to green chemistry adoption

This section pertains to the second sub-question, 'What are the key barriers hindering *green chemistry adoption* within India's textile processing?'. The barriers identified contributed to the understanding of the movement of problematisation within ANT, which focuses on defining the problems within the network. Defining these problems was necessary to inform the development of OPPs that would overcome these barriers. **Figure 5** depicts the four overarching barriers that emerged from the interviews. First, 'Governance' encompasses lack of support, a regulatory gap, and lack of recognition. Second, 'Industry norms' encompasses lack of knowledge, fragmented collaboration, lack of commitment, resistance to change, and a sociocultural gap. Third, 'Operations' encompasses budget misallocation, ineffective due diligence, and ineffective marketing. Fourth, 'Business case' encompasses technological limitations within performance and scalability, and high costs.

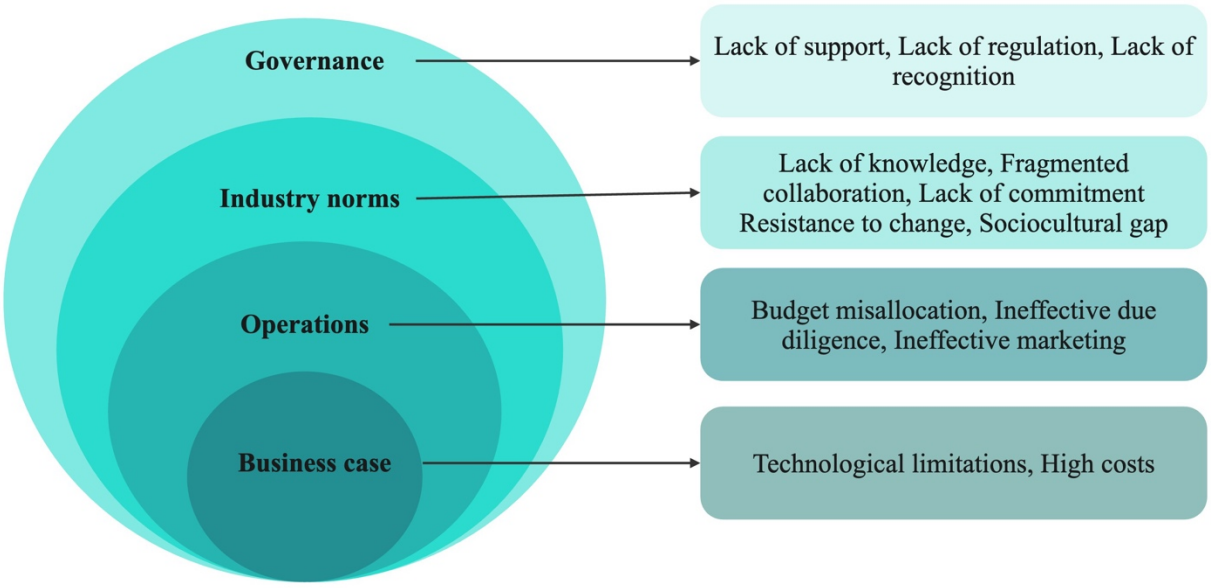

Figure 5: Barriers of green chemistry adoption

Figure depicts the four overarching barriers hindering green chemistry adoption within India's textile processing: Governance, industry norms, operations and business case. Each barrier is further broken down into specific sub-barriers. The link to the figure can also be found in ***Appendix V.***

5.3.1 Governance

Lack of support. The interviews revealed a lack of support from regulatory bodies in the guidance provided, managing certification processes, and fiscal incentives, making actors reluctant to take proactive steps towards GC adoption. An interviewee from a brand expressed, "*sometimes we are looking at things and it takes us a long time to decide which is the right direction to go, because there's always that fear of making a mistake. The challenge with* regulatory bodies *is that they pass a directive, but they should be more explicit about how to support companies moving in that direction and what to do next"*. This highlighted the need for more guidance as the reference to "*fear of making a mistake"* underscored brand's uncertainty in navigating new policies due to the concern on the potential repercussions on their reputation. This sense of fear from brands was perceived by other actors within the network, with a consultant calling for brands to "*be more courages*". Given brands' considerable influence on the network, their uncertainty in following regulatory directives is a cause for great concern.

Next, the interviews revealed a perceived lack of support in managing the proliferation of certifications. An interviewee from a manufacturer stated, "the certification process itself is a challenge. For everything, there are different certifications. So, suppliers feel a lot of audit fatigue". This indicated an increase in frustration from audit fatigue, making them less inclined to invest in certifications. As identified in **Section 5.1.9**, certifications are viewed as assets for gaining access to new markets. However, the multitude of certifications make it unclear which signal the lower impact or relevance to textile processing. Consequently, actors prefer to maintain the status quo and avoid the complexity associated with the certification process.

Finally, regulatory bodies were perceived to provide a lack of support in the form of fiscal incentives, with an interviewee from a brand stating, "they need to invest more in raising awareness of green chemical alternatives," and an innovator urging regulatory bodies "to bring a regulation or provide us with some benefits on the tax side."

Regulatory gap. The interviews revealed the consensus that there is a regulatory gap surrounding chemistry within India. An interviewee from a from a manufacturer stated, "*regulatory changes won't really impact players who don't supply to the international market. So that is a major barrier to GC adoption. Those who work domestically can make their profit from staying domestic*". The extent of this regulatory gap was detailed by an interviewee from a SBP highlighting India do not follow "*an RSL, nor a standardised stringent way of testing for the use of hazardous chemicals, which means that those working domestically are not enforced or encouraged to adopt GC in order to clean up their supply chain".* The effect of this regulatory gap is two-fold; First it gives the impression that sustainability efforts, such as GC adoption, are optional. This undermines the urgency and necessity to reduce the environmental footprint of textile processing, enabling even the manufacturer currently following international regulations to opt with prioritising sales made domestically, where costs are lower and compliance standards are easier to meet. Second, the manufacturers with limited resources may avoid regions with stricter regulations due to the ever-increasing burdens of compliance, overwhelming their capacities and weakening their competitive positions against larger, more resource-intense manufacturers that can absorb compliance costs more easily. Consequently, the knock-on effect is that manufacturers who can comply are selected by brands and form business relationships, while others

are discouraged from exploring GC adoption, even if they have the desire to do so. Consequently, the regulatory gap persists, and the drive towards facilitating GC within the network remains unchanged.

Lack of recognition. The interviews highlighted a critical issue concerning the lack of standardised frameworks for recognising GC. An innovator expressed "*this absence makes it challenging to categorise and showcase such technologies effectively.*" The same sentiment was expressed by another innovator, who called for the government to "*provide a logo and a lab test to distinguish between natural and synthetic dyes*". While this seems contradictory to the perspective of manufacturers and brands which expressed a challenge with the multitude of certifications, this illustrates that the existing regulatory landscape is fragmented, with current certifications do not adequately recognising the unique environmental benefits of different GCs. As mentioned in **Section 5.1.9**, certifications are influential in driving the adoption of GC, as they enhance market access and reputation as brands and consumers look to certifications as an indication of quality, safety, or environmental impact. As a result, this presents a barrier to GC adoption as the absence of recognition creates hesitancy to adopt GC that are perceived as unrecognised products.

5.3.2 Industry Norms

Lack of knowledge. The general perception is that there is a lack of knowledge surrounding the impact of chemicals, minimising the ability to make more informed choices regarding which GCs to adopt and the perceived urgency of adoption. An interviewee from a brand explicitly emphasised the general underestimation of the true impact of textile processing, "*many overlook the extensive role chemistry plays in processing. It's often underestimated*". This sentiment was supported by an interviewee from a SBP, who noted, "*People generally do not really want to use bad chemicals, but they're not aware that a certain chemical is bad versus an alternative. Alternatives that are available are not more expensive than regular chemicals. It's just that the chemical industry is simply not aware that a certain chemical is bad*". This emphasised the lack of the knowledge required to motivate the industry to explore lower impact alternatives.

Additionally, the interviews pointed to an evident gap between academic institutions and industry contributing to the lack of knowledge, with an interviewee for a manufacturer noting, "*if you look at the industry-academia relationship in other countries like the US or even in different parts of Europe, India is not at that point. We don't have a lot of academia collaborative partnerships*". Additionally, it emerged that there is a growing need for specialised skills and knowledge among the workforce, suggesting that there may be limited academic courses that teach the practical knowledge and hands-on experience applicable to textile processing. It was acknowledged that this lack of knowledge has negatively affected the decision-making of the industry, proving to have a more reactive approach to adopting lower impact chemicals. As exemplified by regulatory bodies current approach, an innovator highlighted "*they are not aware of it and need to be educated on the benefits*".

Lastly, the interviews revealed chemical knowledge fails to comprehend the full scope of chemicals' impact, with a consultant observing, "*even brands do not have enough understanding and they are very clearly jumping the gun to create green sustainable claims without fully understanding it completely.*" This was exemplified by the industry's perception of plant-based GCs being clean when in fact it is critical to evaluate at all the metrics that determine how polluting the GC really is. For instance, a consultant emphasizes the importance of determining the biodegradability and impact of a chemical by also measuring "*chemical oxygen demand and biochemical oxygen*

values", which can often be overlooked. This sentiment was echoed by an innovator observing that brands often fail to consider the holistic impact of chemicals, often only focusing "o*n where the garment is being made and not how the garments are being used and the end of life*".

Fragmented collaboration. The nature of collaborations within the network emerged as fragmented, with actors often perceived as working in silos and having surface-level conversations. An interviewee from a brand noted, *"we do interact with different bodies such as the Sustainable Apparel Coalition and our sustainability and legal team will be speaking in the European commission, but do those conversations go deep enough to impact real change or the intended change*". This fragmented nature was also perceived within the supply chain, with an innovator observing, "*if we examine the entire value chain, it becomes apparent that there is a significant disconnect. Brands frequently discuss sustainability initiatives and collaborate with technology companies and other brands to drive changes. However, when we look at the relationship between these layers and the suppliers, it's clear that there's a gap in collaboration towards problem-solving*." This highlighted a transactional approach to current interactions between brands and manufacturers, leading to missed opportunities or a lack of resources being leveraged to facilitate GC adoption. This issue stems from both manufacturers and brands, with an innovator highlighting manufacturers "*often operate within their own bubble, limiting discussions and innovations to internal circles*", while brands are perceived as treating manufacturers "*as mere checklist providers".*

Lack of commitment. The interviews revealed a lack of commitment, specifically from the brands and consumers. An interviewee from a brand noted, "*some brands are going to be very diligent in understanding where their recycled plastic is coming from, and there are brands who will close an eye, right?*" This highlights the disparity in sustainability commitments between brands, contributing to the inconsistencies observed in GC adoption. Additionally, a consultant emphasised, "*a lot of the capsule collections that are being done with brands today have no use unless they are adopting and implementing them in a big way, for at least a year."* This revealed the limited commitment from brands to taking GCs to scale.

Brands' lack of commitment was also perceived by manufacturers noting, "*while trials may be successful initially, scaling up adoption can be challenging as not all brands commit to placing bulk orders; that's where the brands back out*." This behavior shows a lack of trust from manufacturers, which is concerning as brands often need to cover the initial costs (outlined in **Section 5.1.2).** When brands back out, it then places financial pressure on manufacturers, making them reluctant to make the orders in the first place.

Consumers were perceived to be unwilling to spend more on products, indicating a lack of commitment to conscious consumption. As discussed in **Section 5.1.2**, the market is publicly driven, so consumers' reluctance to pay a premium price impedes the adoption of GC, which often comes at a higher cost. Nonetheless, it was acknowledged that ineffective communication with customers contributes to this issue, as it fails to convey the importance of investing a bit more in products that use GC. This lack of clear communication affects consumers' ability to make conscious and informed buying decisions (elaborated in **Section 5.3.3).**

Resistance to change. Resistance to change emerged as a common theme across all the interviews, highlighting a business-as-usual mindset within the network. An interviewee from a brand described this mindset as, "*where you typically see very stubborn behaviors. They do not care; they do not want to change anything. They are happy making the money that they are making. And the more that you discuss, if someone digs their heels in, even when they realise that it's wrong, they just won't change their minds.*" This acknowledged that even with the evidence to show the urgency required for change, a price advantage remains the key motive, driving the resistance to change.

Additionally, an innovator perceived manufacturers' cause for the resistance as "mindset," noting that "*people are often resistant to change, even for minor adjustments. This resistance stems from a need for simplicity in processes, especially since many operators may not be extensively trained*". This underscored the reluctance to change due to the perceived complexity in making alterations to current operations and additional training. Both statements reflect the interest in a price advantage and simplified processes identified in **Section 5.2.1** and **Section 5.2.4**, respectively.

The lack of priority placed on environmental concerns emerged as a contributing to the resistance to change. This is reflected in **Section 5.2**, in which impact savings was not identified as a characteristic that evoked actors' interest and support towards GC adoption. The interviews revealed the extent of this resistance as significant within India due to the reliance of the GDP and employment from the textile market. A consultant observed, "*there is not a lot of drive towards cleaning up the supply chains domestically. Domestic markets are even more price sensitive".* Consequently, this has led to a more reactive approach towards GC adoption within India, with an innovator observing that, "*only when things come to a breaking point will people change. Even if you give them warnings and you see environmental disasters already happening, including floods and forest fires, people do not change*".

Sociocultural gap. A sociocultural gap within India emerged as a significant barrier to GC adoption, driven by gender and generational dynamics. Regarding gender dynamics, the interviewee detailed experiences of the struggle with her advice being taken seriously by males, specifically with owners of Indian manufacturers. She expressed, "e*ven as a woman of Indian descent, it's very hard to work in India... and that type of mindset prevents growth...you will not be able change it within one day and to be prepared to continue to fight the good fight*". This explicitly underscored the slow progress towards GC adoption when recommended by females within the industry. Regarding generational dynamics, an interviewee from a brand highlighted progress towards adopting GC is highly dependent on "*the age of the owners of the facilities",* with the younger generation expressing more interest towards GCs. The younger generation was perceived to b*e "acutely aware that if they continue down this path, even if it's profitable now, they will ostracize themselves from ever attracting business*". Whereas "*the older school mills, they just want to make as much money as they can for as long as they can. When it is no longer profitable, it is okay. So, there's no real incentive to want to change*", revealing a more financially driven approach to textile processing.

5.3.3 Operations

Budget Misallocation. The interviews revealed that brands often have substantial budgets to spend on innovations but fail to spend them effectively. A consultant expressed the concern that, "*whether they are spending it on the right people is the question...I know at least seven brands who all spend money on the same thing are. Everyone is doing the same experiments again and again and again*". This highlights the tendency for multiple brands investing in the same trials, thus wasting resources and minimising the exploration of other GC, leading to missed opportunities. This underscores the problematic effect of brands working in silos, as mentioned in S**ection 5.3.2,** rather than using the opportunity to build upon each other's findings and collectively drive meaningful advancements.

Ineffective Due diligence. The interviews revealed that the current due diligence process is often ineffective due to transparency concerns, misleading LCAs and inaccurate base cases, and lack of effective trials. First, Suppliers and brands often withhold information from each other and may be hesitant to disclose certain details because of concerns about maintaining a competitive edge and protecting intellectual property rights. An interviewee from a SBP noted, "*the more transparent you are, the better for the other person to know how green you are. But sometimes, we also agree that these are certain chemicals you don't want to disclose because you want to keep your monopoly which you have spent a lot of money, hours and, time in producing"*. The underscored the trade-off between transparency and protecting proprietary information hindering the ability to make clear comparisons and creating a lack of clarity for decision-making concerning GCs.

Secondly, the interviews revealed that it is difficult to distinguish the true impact savings of GCs owing to ineffective ways of making case-to-case comparisons. One of the essential tools for conducting these comparisons is through LCAs (refer to S**ection 5.1.10**). However, an innovator expressed, "*the scope and goals of LCAs can vary, leading to inconsistencies in comparison".* This was echoed by a consultant emphasising, "*there will be a lot of LCAs that will be created in the name of LCAs but created with the wrong boundaries and wrong interpretations.* Additionally, the expensive and resource-intensive nature of LCAs often means that they *"may not always be feasible for innovators*". Both these statements underscored that LCAs are not viewed as a definitive metric for assessing technology as they can be misleading or unachievable to conduct due to resource constraints, hindering the effectiveness for case-to-case comparisons. Additionally, a consultant noted, "*products which are claimed to be sustainable against a particular scenario may not be necessarily sustainable against another scenario"*, revealing a inaccurate base cases used to compare GCs with the chemicals they intend to replace, hindering the adoption of GCs as they do not effectively present the true impact savings. This was exemplified by salt-free dyeing being compared with exhaust dyeing, when making a fair comparison requires comparison with continuous dyeing methodologies.

Lastly, a similar concern was expressed on the current effectiveness of trials, with a consultant raising concern that *"sometimes innovations do not have existing lab trials because it's too early so it's important to have it in their portfolio and create it*". However, this is often the case especially for early-stage innovations as they are "*constantly developing*". Additionally, as outlined in **Section 5.1.9**, the reference to trials as tools to "*keeping the industry engaged*" suggests that trials may merely be used as tools for engagement showcasing changes on the surface, rather than necessarily committing to substantial changes.

Ineffective Marketing. The interviews revealed a failure to bridge the gap between GCs and consumer awareness. A consultant explicitly noted, "*Innovators are not being promoted very well and that's the difficulty we have today*." As identified in **Section 5.1.2**, consumers are significantly influential in driving the market. However, without accurate knowledge or motivation, they cannot positively influence GC adoption. According to an innovator, this ineffective communication is since communication "*has been built over a period of 50 years*," underscoring the need for change as it currently fails to convey the implications of consumer purchasing decisions and discern what is genuine about current chemicals. Additionally, brands' storytelling about the aesthetics of GCs is ineffective, creating confusion with their misleading claims. An interviewee from a brand exemplified this, stating, "y*ou need to be able to tell the story to explain why it looks like this and if the dyes are mixed with regular dyestuff to achieve the color that you're looking for, then you've already diluted your story*". This highlights the contradiction between the expected irregularities of bio-based GCs and the perfect appearance of products mixed with synthetic GCs. Lastly, an innovator revealed that, "*brands have become very clever. So, they are not genuinely communicating how a product is made. There's a lot of greenwashing which goes on in between*," further contributing to the miscommunication and hindering consumers from making conscious, informed choices towards GCs.

5.3.4 Business Case

Technological limitations. Technological limitations emerged as a significant barrier to GC adoption. An interviewee from an industry association observed there is, "*reluctance in India to adopt green chemistry because they tend to be more expensive, and there is a performance element that is reduced"*, highlighting the perception that GCs are incapable of matching industry performance standards. Additionally, an interviewee from a brand highlighted, "*for bigger brands there is not nearly enough volume to run through our types of machines and processes because we don't do orders of 50,000 or 100,000 pieces, we do millions of pieces*", highlighting the inability of GCs to scale to the amounts required within the industry. The sentiment towards these technological limitations was mirrored among all participants, but the issue was amplified by the network's unwillingness to make compromises to accommodate GCs. In fact, an interviewee from a brand explicitly stated, "*we cannot compromise on quality*" in reference to lower performance being unnegotiable. This perception was also reinforced by the findings in **Section 5.2.2**, which identified performance as a crucial characteristic for evoking actors' interest and support towards GC adoption.

High Costs. High costs emerged as a significant barrier to GC adoption, primarily due to the premium associated with GCs. An interviewee from an industry association pointed out the pricing challenge, noting, "*pricing is not even close to the incumbents or the synthetics. We still do not know how to solve this*". The interviews revealed that brands play a significant influence on this challenge due to their cost structures. An interviewee from a brand detailed their strategy of comparing regional prices and choosing manufacturers based on the lowest cost that meets their pricing targets. his approach disadvantages regions like India, where "*manufacturing costs in India cannot be compared to those in Bangladesh, where labor costs are cheaper"*. Consequently, manufacturers may be reluctant to adopt GC, fearing the loss of business relationships with brands due to premium prices. This concern was echoed by another brand

interviewee, who noted, "*cost poses a major challenge for GC projects because it significantly impacts manufacturers and their procurement parameters*". However, a broader economic challenge occurring worldwide emerged as highly influential in this barrier, with a consultant highlighting, "d*aily expenses are increasing worldwide, and governments are raising minimum wages accordingly. This increase impacts manufacturing process costs"*. This underscored the need for collaborative solutions to reduce the financial burden on brands owing to their responsibility of covering costs and to provide more financial security within the supply chain to facilitate the GC adoption.

6. RECOMMENDATIONS FOR FACILITATING GREEN CHEMISTRY ADOPTION

This section pertains to answering the main research question, 'How can the adoption of green chemistry be facilitated in India's textile processing?'. To answer this, the responses from each sub-question were used, along with the responses given by the participants on potential solutions. These proposed solutions informed the development of the recommendation as the participants were all selected to represent focal actors. Therefore, it was anticipated that their visibility on the network would allow them to give actionable insights. The combined input from both led to the development of six actionable recommendations each made up of OPPs - crucial steps that various actors would need to engage in to contribute towards facilitating GC adoption. Each OPP was created with the intention to address or leverage the characteristic outlined in **Section 5.2**, address the barriers outlined in **Section 5.3**, and enrolled a selection of actors whom, according to **Section 5.1**, were most adept to the assume the role or responsibility. This was based on the premise that the actor was either willing to accept the role or most suitable due to their influence or capabilities. Figure 6 depicts six actional recommendations; meaningful collaborations, supportive governance, education reform, redefining evaluation metrics, maximising trial outcomes, and managing costs. It is important to note that the recommendation are not in order of priority, nor do they address all the barriers identified within the study. However, they provide a critical starting point for actionable steps towards facilitating GC adoption. The justifications behind each OPP are covered in the following sections.

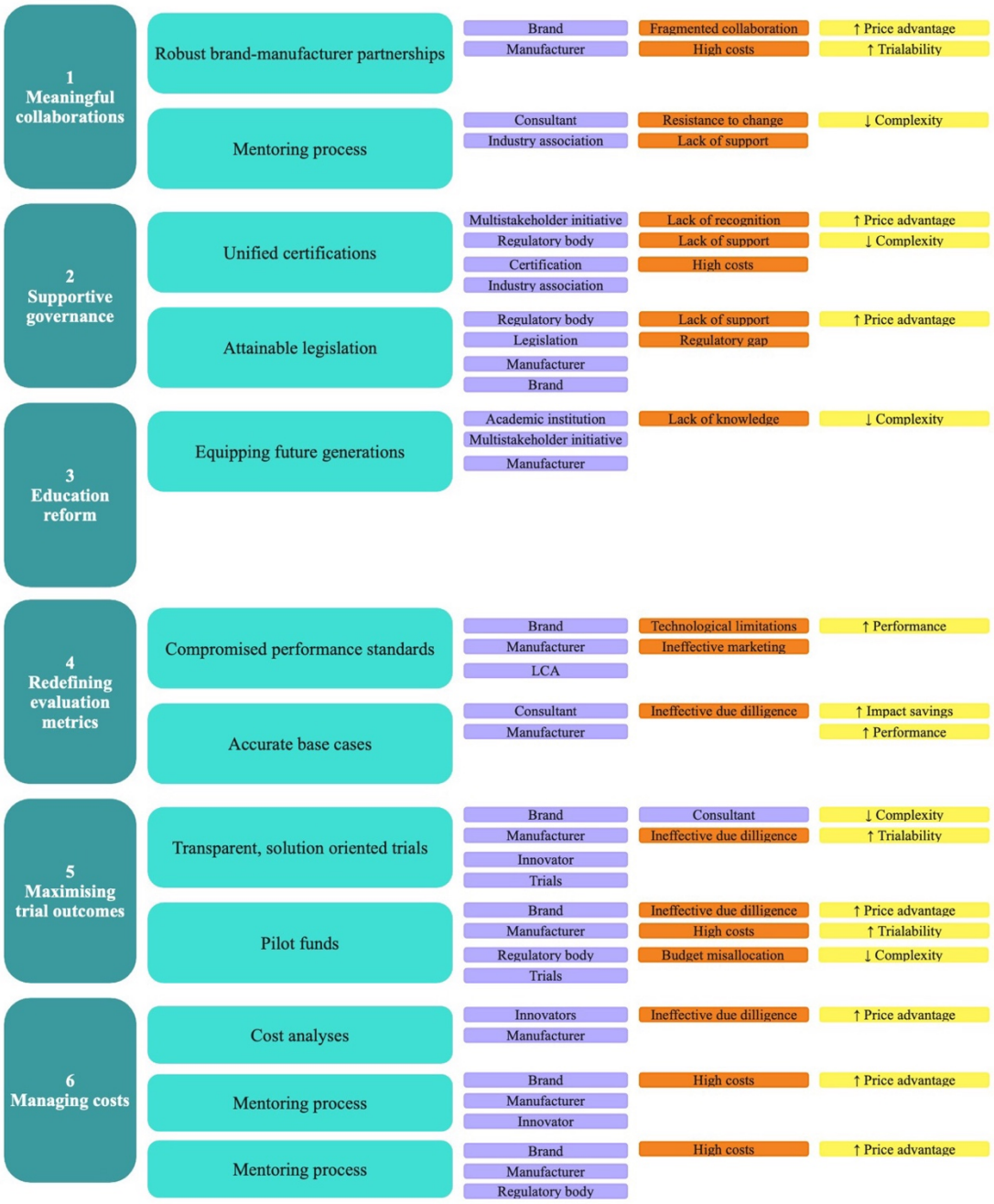

Figure 6: Recommendations for facilitating green chemistry adoption

Figure depicts the six actional recommendations (Green); meaningful collaborations, supportive governance, education reform, redefining evaluation metrics, maximising trial outcomes, and managing costs. Each recommendation is made up of obligatory passage points (blue) outlining the actors enrolled (purple), barriers it addresses (orange), and characteristics to evoke actors' interest and support (yellow). The recommendations are not placed in hierarchy, but are all of equal importance. The link to the figure can also be found in **Appendix V.**

6.1 Meaningful Collaborations

According to an interviewee from an academic institution, collaborations are a "*necessity and important for survival*". However, current collaborations are "*transactional*" and "*fragmented*", lacking the depth to impact real change. This needs to shift to **meaningful collaborations** which are solution-oriented, resulting in clear, common objectives that enable the sharing of resources. As depicted in **Figure 6**, two OPPs are crucial for meaningful collaboration.

First, **robust-manufacturer partnerships** are crucial. Currently, the **barrier presented is fragmented collaborations** and **high costs**. These hinders the ability to problem-solve and focus efforts on a common objective. An innovator suggested that robust partnerships need to *"leverage resources and knowledge to go beyond transactional relationships, to push boundaries, and drive meaningful change in the industry*". For these robust partnerships to be successful it is recommended that **brands and manufactures are enrolled** with a common objective on lowering the environmental impact of their operations. Brands currently set chemical requirements to help them select a manufacturer to become their supplier. Instead, these requirements should be used as a benchmark to tailor their engagements with each manufacturing partner. With the manufacturers that are non-compliant they must provide the necessary financial support for them to meet industry standards. Whereas, with the manufacturers that are compliant, they should encourage them to leverage their ability to run chemical analyses and trials collaboratively to successfully navigate the technical challenges encountered in the early stages of GC development. Once all their manufacturing partners meet the requirements, they can raise the benchmark and repeat the process. This will ensure continuous improvement towards establishing a lower impact supply chain and facilitating GC adoption. Robust partnerships have the ability to enhance actor's interest and support towards GC adoption as it **enhances the perceived price advantage**, either from sharing the financial burden or from benefiting from the cost savings obtained through the impact savings that are realised. Additionally, by aligning efforts to coordinate more targeted and effective trials, this will avoid redundant trials and **enhance the perceived trialability** of GC.

Second, a **mentoring process** is crucial. Currently, the **barrier presented is resistance to change** due the perceived complexity concerning adjustments to current operations or additional training required within the workforce. Additionally, there is notable **lack of support** due to the minimal guidance provided. This makes brands and manufacturers hesitant to make actionable steps. To overcome this a consultant explicitly recommended the initiation of "mentoring processes". This was echoed by an interviewee from a brand which urged, "i*t would be great to see brands having access to organisations that can help them at nominal fees to make these kinds of adjustments within their own structures.*" For this mentoring process it is recommended that either **consultants or industry associations are enrolled together with manufacturers and brands.** Consultant are deemed adept due to their "*experience of managing facilities*" and technical expertise, while industry associations are deemed suitable due to their due to their understanding of the industry and ability to leverage their network to support and develop technologies. This mentoring process has the ability to enhance actors' interest and support towards adopting GC since it **minimises the perceived complexity** around GC.

6.2 Supportive governance

The interviews uncovered a lack of effectiveness from regulatory bodies, reflected by the current fatigue towards certifications, and the regulatory gap within India. This has created a sense of uncertainty among actors, preventing them from taking actionable steps towards GC adoption. To address this a more **supportive governance structure** needs to be created, which simplifies processes and allows for regular feedback to enforce mandates that are attainable to the majority. As depicted in **Figure 6**, two OPPs are crucial for a supportive governance structure.

First, **unified certifications** are crucial. Certifications are seen as assets to access markets, but currently there is a multitude of them, incurring high costs and uncertainty. Therefore, the barrier faced is **high costs, lack of support, and lack of recognition**, as certifications fail to showcase the true benefits of GCs. Unified certifications would require merging existing certifications into more comprehensive yet streamlined ones. This will ensure that the impact of chemicals is more accurately communicated, enabling GCs that are currently unrecognised or badly represented to be compared fairly across the industry. Thus, increasing the attractiveness of GCs within the network. For the unification of certifications, it is recommended that **certifications, regulatory bodies, MSIs, and IAs are enrolled**. MSIs and IAs are adept due to their abilities to drive collaborative conversations and projects, with an interviewee from a brand, explicitly highlighted MSIs as positioned to "facilitate collaborative conversations", while an innovator described industry associations as enabling, "*a common ground where their message can be spread easily...being part of these organizations' goals ensures alignment and collective effort towards achieving success*". Additionally, to ensure that these frameworks are enforced and legitimised, regulatory bodies need to be enrolled as they serve as facilitators of "*driving a certain type of behavior*". Unified certifications have the ability to evoke actors' interest and support towards GC adoption since it **reduces the perceived complexity** surrounding certifications and **enhances the perceived price advantage** by reducing the costs typically required to accommodate each certification. A recent example the unification of certification is being carried out by Textile Exchange (Textile Exchange, n.d.). This standard aims to merge six existing standards (Global Recycled Standard; Recycled Claim Standard; Responsible Wool Standard; Responsible Mohair Standard; Responsible Alpaca Standard; Responsible Down Standard) by 2025. They have acknowledged that this unification will enhance the ability to track and communicate progress more effectively.

Second, **attainable legislation** is crucial. Currently, the effectiveness of legislation remains questionable, as the conditions and requirements are not favourable for the entire textile processing network to meet compliance. This is owing to the disconnected nature of regulatory bodies preventing them from obtaining detailed insights to establish legislation that are practical applicability to the majority. Therefore, the barrier that is faced is a **regulatory gap** that often disproportionately affects smaller or less advanced manufacturers with fewer resources. To create attainable legislation, it is recommended that **legislation, regulatory bodies, manufacturers, and brands are enrolled**. Enrolling legislation is self-explanatory, supported by the consensus that they are required to "*force people to change*". Regulatory bodies are adept due to their authoritative position for enforcing legislation and creating a platform for manufacturers to voice their concerns. Brands, with their enhanced visibility of the supply chain, should assist in identifying manufacturers for whom legislation has been unattainable and encourage them to voice their concerns. While manufacturers should proactively voice their concerns and the support they require. Ultimately, this will enable

a channel of regular feedback for regulatory bodies to reflect on the network's true capabilities and make legislation more attainable via the reduction of costs and resources required to achieve compliance. This has the ability to evoke actor's interest and support as it minimises the financial strain, therefore **increasing the perceived price advantage** of GC adoption.

6.3 Education reform

The interviews revealed that a barrier to GC adoption is the inability to make informed decisions on GCs, owing to a lack of knowledge. This **lack of knowledge** exists due to the noticeable gap between AIs and the rest of the industry within India. To overcome this an **education reform** is needed. As depicted in Figure 6, one OPP is crucial to **equip future generations** with the specialised skills and knowledge to enter the workforce. To equip future generations **AIs, MSIs, and manufacturers are recommended to be enrolled.** Via engaging in this education reform, these actors can leverage a mutually beneficial relationship in which the curriculum becomes enriched with practical knowledge, boosting students' job readiness and integration into the industry. While, also providing the industry with fresh insights and innovative solutions developed by students. AIs are necessary as the main educators to the next generation of engineers, designers, and managers, enabling them to effectively tackle industry demands. MSIs should leverage their ability to facilitate collaborative conversations to identify industry needs and contribute to the curriculum so that it corresponds with the gaps within the industry. Lastly, manufacturers should leverage their technical capability to contribute technical knowledge and practical hands-on training within the courses. Thus, addressing the gap between theoretical knowledge and practical application in real-life settings. Equipping future generations can evoke actors' interest and support towards GC adoption as it will ensure future generations entering the workforce are better prepared and no additional or extensive training for the workforce is required. Thus**, decreasing the perceived complexity** associated with GC adoption.

6.4 Redefining evaluation metrics

Currently GCs are not perceived as favourable to the industry, hindering their adoption. This is highly dependent on their inability to meet industry performance standards and the use of inaccurate bases cases. To overcome this, it is necessary for **evaluation metrics to be redefined** to accurately assess the viability of GCs in comparison to the chemicals they intend to replace. As depicted in **Figure 6**, two OPPs are crucial to redefine evaluation metrics.

First, **compromised performance standards** are crucial. There is consensus that to evoke actors' interest and support, industry performance standards must be met. However, this is often not the case for GCs, making **technological limitations a key barrier** to adoption. To overcome this, the industry must be willing to compromise aspects of performance with the environmental benefits that can be obtained from adopting GCs. This necessitates realistic expectations to be set about product longevity and environmental impact through analyses that determine the impact of compromising on performance for lower-impact chemicals. For example, an innovator suggested considering the average lifetime of a garment when assessing performance metrics such as colour fastness. Given the tendency of natural dyes to fade with time, highlighting this characteristic as a means of improving the biodegradability of the garment can effectively capture the environmental benefits. To determine which aspects of performance can be compromised, **brands, innovators, and LCAs are recommended to be enrolled**. LCAs are

required to communicate impact data which can be used to support claims that outweigh the minor flaws within performance. Innovators must support the data collection process for LCAs, due to their knowledge on the GCs they develop. Finally, brands can contribute financially and help demonstrate the benefits of GCs by shifting the perception of the performance standards considered as acceptable. Compromising performance standards has the ability to evoke actors' interest and support towards GC by **increasing the perceived relative advantage associated with performance.**

Second, **accurate base cases** are crucial. Currently a barrier is ineffective due diligence due to the inability to accurately assess the viability of GCs and sustantiate claims on their impact savings. As noted by a consultant, establishing accurate base cases ensures that all actors involved understand what chemical alternative it is being compared with, whether it's universally applicable, the impact it is creating, and its limitations. To establish accurate base cases, it is recommended that **manufacturers and consultants are enrolled.** Manufacturers should utilise their technical expertise and knowledge of facilities to establish appropriate criteria for testing the base cases in actual facilities. While consultants' industry experience and technical background should be leveraged to support the claims of the base cases' applicability. Establishing accurate base cases has the ability to evoke actors' interest and support towards GC by increasing the perceived **relative advantage associated with performance and impact saving.**

6.5 Maximising trial outcomes

From the interviews it was evident that trials are significant in facilitating the adoption of GC. However, concerns were raised concerning the current state of trials ranging from; their effectiveness in navigating technical challenges rather than being used for mere engagement, the costs of trials, and either the extensiveness or lack-of trials for GCs. Due to the value trials hold **maximizing trial outcomes** is a must. As depicted in **Figure 6**, two OPPs are crucial to maximise trial outcomes.

First, **transparent and solution-orientated trials** are crucial. Currently a **barrier faced is ineffective due diligence.** Therefore, the goal of trials should be shifted from merely engaging actors to proactively identifying and resolving issues to obtain favourable results. An interviewee from an industry association noted, that once brands "*don't get good trials they lose interest. It is important to have a line of open communication*". This underscores the significance of maintaining open communication throughout the trials so that the actors involved are aware of the costs and value of proceeding with trials. To conduct transparent and solution-orientated trials, it is recommended that **trials, brands, manufacturers, consultants, innovators, and industry associations should be enrolled**. Brands should oversee these trials to contribute to defining the results expected to be obtained based on the insights they hold on customer expectations, as well as contribute financially. Manufacturers are central for the practical execution of trials by providing the necessary machinery, as well as navigating technical challenges. Consultants' industry and technical experience is essential to ensure that the trials are rigorous, enabling meaningful improvements and identifications of issues. Innovators provide the GCs for testing and support in executing the trials. Lastly, industry associations' ability in managing collaborative projects should be leveraged to ensure effective communication between those involved, enabling the trials to run smoothly. Transparent and solution-orientated trials have the ability to evoke actors' interest and support as by increasing the efficacy of trials it will **reduce the perceived complexity**

associated to GC. Additionally, this will contribute to **increasing the perceived trialability** of GCs as it will increase the likelihood of favorable results.

Second, establishing **pilot funds** are crucial. Currently, the barriers faced are **high costs** and **budget misallocation** attributed to trials. However, pilot funds can alleviate the financial burden of conducting trials by distributing the costs and perceived risks amongst multiple actors. This can increase the willingness to invest in testing a wider variety of GCs. Additionally, the fund can encourage collaboration and sharing of findings, preventing the repetition of trials. To establish pilot funds, it is recommended that **trials, manufacturers, brands, and regulatory bodies** are enrolled. Manufacturers should contribute their practical insights and technical capabilities, leveraging the fund to experiment with new chemicals without bearing the full financial burden or relying solely on individual brands. Brands are essential due to their understanding of customer expectations. They can signal which GCs should be trialed and help drive market demand. Once favorable results are obtained, brands can also bring the GCs to market and benefit financially from both the impact savings and access to new customer bases. Regulatory bodies must provide additional funding and use their authoritative and non-affiliated nature to ensure funds are spent effectively. Establishing pilot funds has the ability to evoke actors' interest and support towards GC as better budget allocation will **increase the perceived trialability**, **increase the perceived price advantage** due lower up-front costs, and lastly minimise the number of trials being conducted, in turn, **reducing the perceived complexity** associated with GC adoption.

6.6 Managing costs

A key **barrier to GC adoption is the high costs** compared to traditional chemicals. However, it is now well understood that until GCs reach economy of scale it is unlikely that up-front costs can be reduced. Therefore, mechanisms for **managing costs** need to be established. As depicted in **Figure 6**, three OPPs are crucial for managing costs.

First, **costs analyses** are crucial. These analyses need to be introduced early on during the due diligence phase to enhance the attractiveness of GCs. As noted by a consultant, through these analyses it will determine "*how cost can be analysed and reduced*". By demonstrating the long-term financial benefits realised from the impact savings it helps present a compelling economic case to brands so that they see the value in overcoming the initial up-front costs. To conduct cost analyses, it is recommended that **innovators and manufacturers are enrolled**. As the developers of GCs, innovators need to leverage their knowledge on the GC to predict and model how these savings could manifest over time to construct theoretical cost analyses. While manufacturers should conduct lab trials within their facilities to provide real-context data and evidence to support the theoretical analyses made by innovators. Cost analyses have the ability to evoke actors' interest and support towards GC adoption since they better position GC to have an **increased perceived price advantage**.

Second, **collaborative business models** are crucial. There is currently a range of collaborative business models which can be implemented to reduce the financial burden on actors. As noted by an interviewee from a brand it is important to consider how to invest together "*...because at this point a lot of things are new and they will cost a lot, but at one point we'll get to this critical mass, and it will no longer be as expensive as it is today*". To establish collaborative business models **the actors enrolled depends on the actors involved, and the resources or expertise that is missing.** For example, **a partnership model may enroll manufacturers and innovators.** This would leverage

the innovators' expertise on GCs and the manufacturers' existing facilities and technical expertise. This is particularly beneficial when the innovator lacks the necessary finances or facility to carry out further R&D. While the manufacturer can benefit from obtaining impact savings when the GC is adopted successfully. Additionally, a **partnership model could enroll both brands and manufacturers**. An example provided by an interviewee from a brand. was a brand committing to purchase 50% of a supplier's yield over the next few years. The commitment from the brand ensures a guaranteed revenue stream for manufacturers, while sharing the financial burden reduces the up-front costs for the brand. Thus, encouraging both actors to invest in GC adoption. Beyond partnerships, joint ventures and licensing also represent collaborative business models which can be implemented strategically to alleviate the financial burden. Collaborative business models have the ability to evoke actors' interest and support as sharing costs **increases the perceived price advantage**.

Third, introducing **fiscal incentives** is crucial. Currently, both brands and manufacturers have the role of covering the costs during the development and adoption of GCs. This places significant financial burden on them and discourages them from adopting GCs. As outlined in **Section 5.1.5**, participants from both actor groups acknowledged the value fiscal incentives could have in positively influencing them to invest in GCs. To introduce fiscal incentives, it is recommended that **regulatory bodies, manufacturers, and brands are enrolled**. Regulatory bodies are to be enrolled to establish the criteria for these fiscal incentives, aligning them with the broader goal of facilitating GC adoption. Whereas, as both manufacturers and brands are the direct beneficiaries of fiscal incentives, they need to be enrolled to help define the criteria for the development of fiscal incentives. By establishing a channel for regular feedback with regulatory bodies, this will allow fiscal incentives to be established that meet their needs and encourage further investments in GCs. Fiscal incentives have the ability to evoke actors' interest and support towards GC adoption as by sharing costs it **increases the perceived price advantage**.

7. DISCUSSION

7.1 Practical contributions

This research provides practical contributions by offering six actionable recommendations for several reasons. First, the participants were selected based on the criteria specified in **Section 4.3.2**, which were aimed to identify focal actors. These individuals had decision-making position, such as executives, CEOs, and managers (Tatnall & Burgess, 2011; Zein et al., 2022). As decision makers with visibility over the networks' operations, it was expected that they would provide valuable and applicable insights. Second, the insights provided by the participants led to the identification of the barriers described in **Section 5.3**. Their recognition of these barriers indicated their acknowledgment in that fact that solutions need to be developed to overcome them. Considering this, recommendations were formulated to overcome the identified barriers, instilling greater confidence that, with sufficient support, these recommendations may be successfully implemented. In addition, the recommendations did not include the incorporation of new actors nor establish additional roles which were not identified within the analysis. Instead, the recommendations focused on leveraging the strengths of the actors through the roles they perceived to already hold, were most suitable for, or were willing to accept. This instills confidence in the feasibility of incorporating the recommendations into the current network with minor adjustments. Finally, the recommendations were built around the characteristics identified to evoke actors' interests and support. By ensuring that the recommendations are in line with these characteristics, there is a higher likelihood that they can be implemented, as they are not only feasible, but also attractive to the actors involved.

7.2 Theoretical Contributions

The goal of the study was to address the literature gap around the adoption of GC and provide actionable recommendations to facilitate their adoption within India's textile processing. By doing so, it extended current theoretical insights in several ways.

First, previous research has identified barriers to GC adoption, although they are applicable to the textile industry on a broader level (Rahman et al., 2019; Shahzad et al., 2022; Ullah et al., 2021; Veleva & Cue, 2019). Therefore, the objective of sub-question 2 was to identify the barriers that exist specifically in India's textile processing to allow for tailored recommendations for facilitating GC adoption. As noted by Xia et al., (2019), identifying barriers is a crucial step in developing strategies to allow innovations to scale. **The barriers identified in this study emerged through the data collection that set out to obtain an in-depth understanding of the unique sociocultural and technical factors that shape the network. Therefore, even if the industry or other researchers do not implement the recommendations highlighted within this study, there is confidence that the barriers identified within this study serve as a crucial starting point for future research.** For example, the interviews revealed a significant gap between AIs and the rest of the actors within the industry in proportion to other regions of the world, resulting in the lack of knowledge about the impact of chemicals and specialised skills within the workforce. This finding exemplifies that the barrier is highly dependent on the Indian region and may not be applicable to other regions of the world.

Second, previous research has often addressed barriers to innovation adoption through a finanical or policy lens. **However, this study revealed the significance of a more holistic approach to examining the barriers, considering all the actors involved.** For example, the findings revealed a regulatory gap within India, leading to compliance being unattainable and discouraging smaller or less advanced manufacturers from adopting GCs. Examining this barrier solely through a policy lens would not accurately capture all the factors involved. Whereas, through the socio-technical lens, it emerged that regulatory bodies are perceived as disconnected from the rest of the network, which contributes to the ineffectiveness of the legislation they enforce by reducing the extent to which actors can provide feedback on the attainability of compliance. Additionally, the research also demonstrated that current collaborations are fragmented, with actors typically engaging in surface-level conversations or working in isolation. This had led to wasted resources and a lack of problem solving. These results emphasised the importance of the data obtained for sub-question 1, which was dedicated in exploring the roles and interactions of all actors. By mapping out these roles and interactions, as well as gaining an understanding in the motivations and limitations of each actor, it enabled the development of recommendations that outlined OPPs that leveraged different actors' strengths to facilitate GC adoption and aligned their interests. The socio-technical approach, which considers the perspectives, interpretations, interests, and demands of all actors in the network, facilitated the comprehension of these roles (Aka & Labelle, 2021). Thus, this approach provided confidence in the recommendations and supports the use of the socio-technical lens as a methodological framework to study innovation adoption within research.

7.3 Limitations

A limitation of this study was the **definition of GC**. The study defined GC as chemistry which has a lower environmental impact (Karimi Takalo et al., 2021). However, as highlighted in Section **5.1.9**, it became evident that there is **no universally accepted definition for GC**, as it adapts in response to technological advancements and the regulatory landscape. The absence of a precise definition is a result of the ever-changing nature described as a whirlwind in ANT, and the iterative nature of innovation development. (Akrich et al., 2002b). The emergence of varying definitions is promising because it **indicates that GC is adaptable and can be enhanced to better facilitate its adoption** within the network. However, to assess the viability of GCs in the textile industry, actors use specific metrics related to the chemical requirements, impact and performance. Therefore, to build a more applicable approach to adoption that aligns with the current expected metrics, **more detailed specifications should have been elaborated upon in the study**. This would have **enabled a more comprehensive assessment of the role of GC and uncovered further insights into the interests of the actors concerning the supposed inherent characteristics of GCs at a more detailed level.**

The second limitation of the study was the **diversity of the sample**, which was constrained by the university's time restriction. To minimise this, the triangulation of FFG's internal sources and Internet sources was employed to obtain a reliable sample. This proved successful as it still allowed conflicting views to emerge. For example, it was revealed that there was a clear contrast among brands and manufacturers who were leading the way in meeting compliance or exceeding them and those for whom compliance is unattainable due to resource constraints. **However, this highlighted a research gap that needs to be explored further to provide a more holistic view on the differing perceptions and experiences of manufacturers and brands.** To minimise this, the decision was made to prioritise

interviewing additional participants from the brand actor group over consumers, as conflicting insights did not emerge. However, it was not possible to recruit further participants from manufacturers.

Finally, another limitation was **access to participants**, specifically smaller manufacturers and regulatory bodies. Smaller manufacturers operate on tighter budgets and limited resources. This means they are likely family-owned or predominantly depend on operating domestically, due to the challenges of meeting international compliance standards. Therefore, various factors may have limited their accessibility. For instance, an interviewee from a brand noted a sociocultural gap among Indian manufacturers. This may reflect in resistance towards adopting GC, resulting in a reluctance to participate in the study. Additionally, with primarily operating domestically is can be anticipated that there may have been language barrier, further influencing the lack of responses. For regulatory bodies, the study revealed an evident disconnect from the network. This was reflected in the difficulty of recruiting participants and the apprehension observed from the participants that a contact would be retrieved. Like the manufacturers, various factors could explain the lack of access. There is an apparent regulatory gap within India which suggests that GC is not prioritised, resulting in a reluctance to discuss the topic, regulatory bodies are inclined to maintain an authoritative stance, and potential language may exists limiting the response rate. Nonethless, **this revealed a research gap within these actors groups that requires further research in order to better understand the barriers faced by these groups**. Namely, resistance to change, sociocultural gap, and the regulatory gap.

7.4 Future research

There are various directions for future research to address the limitations of this study. First, to address the limitations around the definition of GCs, future research can **focus on defining the specific metrics that a chemical is required to meet industry expectations, as well as define those required to be considered a GC**. This would allow for a more thorough evaluation of the capabilities of GCs and reveal the interests of the actors at a more granular level. **By establishing precise metrics for both, it can then become possible to establish more accurate expectations on which areas of performance can be compromised.**

Second, there are **evident differences among brands and manufacturers leading in space and those with fewer resources**. Future research could **focus on a wider selection from these actor groups to address the diversity** of GC adoption among them. This could involve making comparisons on the rate of GC adoption and exploring how GC adoption can be facilitated in a more focused approach, such as through an organisational perspective. Exploring these differences in more detail could provide deeper insights into the specific challenges and opportunities faced by various actors within the network, thereby enabling tailored strategies for promoting GC adoption.

Third, the relationship map was successful in identifying the actors within the network to ensure that their role and influence were analysed within the study. However, **the lack of participants for both regulatory bodies and consumers meant that their perceptive was underrepresented, potentially overlooking key insights.** Future research would benefit from exploring the disconnect of regulatory bodies. This is crucial, as the industry relies heavily on regulatory bodies, and as evidenced by the lack of GC, the industry cannot depend on proactive voluntary actions. Therefore, exploring the cause of this disconnect and the barriers faced by regulatory bodies is essential. The key questions to explore include: What causes the disconnect between regulatory bodies and the rest of the network? What barriers do regulatory bodies face when implementing legislation? Despite having enough evidence to enforce stricter

regulations, why are they not being implemented more stringently and at a faster rate? How can regulatory bodies create regular feedback channels? For consumers, the interviews revealed that the network is "publicly driven", and the blame is often placed on brands' ineffective marketing for their lack of conscious consumption. However, consumers possess the resources and platforms provided by industry associations and MSIs to educate themselves, yet they fail to engage with them. Future research could explore strategies to better engage consumers in consuming more consciously. A key questions to explore could be: What factors influence consumer engagement to these platforms? Both **studies would benefit from conducting either bigger or smaller, more targeted research on each actor group to investigate their roles further.**

Finally, **Mobilisation was beyond the scope of this study**. Future research could **test the applicability and acceptance of the recommendations made in real-life contexts** using longitudinal studies. For instance, one way to examine 'unified certifications' could leverage the current unification of certifications being carried out by the Textile Exchange. Research could follow the impact of innovation adoption pre-and post-unification. Nonetheless, the area that urgently needs validation is the effect of redefining evaluation metrics. There is consensus that current performance standards are not being met, which underscores a major barrier and a lack of willingness to compromise. Future studies **need to explore whether performance requirements can be compromised to accommodate GCs. If these requirements cannot be compromised, it may suggest a fundamental problem with the intrinsic technological capabilities of GCs.**

8. CONCLUSION

This study explored how the adoption of GC could be facilitated within India's textile processing. To do this, the study mapped both the human and non-human actors, identified each of their roles and interactions, revealed barriers to GC adoption, and leveraged their respective strengths and interests to provide actionable recommendations.

Textile processing is undoubtedly complex and filled with uncertainty, spanning from manufacturers to consumers. However, despite substantial evidence emphasising the environmental impacts of textile processing, there continues to be a business-as-usual mindset. A key takeaway from this study is that every actor has a role to play that can influence the trajectory of GC adoption, and this influence is largely motivated by their own self-interests. Therefore, the presence of leaders in the space meeting industry standards and adopting GCs is not impressive. Instead, it only underscores that a business-as-usual mindset persists because blame continues to be shifted onto others for the inability for not fulfilling their roles, rather than holding themselves accountable. For example, brands recognise the presence of the 'champions' within their companies who genuinely want to make a difference but continue to prioritise up-front financial benefits. Regulatory bodies have the authority to force behavioural change and the means to gather feedback from the rest of the network to make legislation more attainable, yet they continue to remain disconnected. Lastly, brands are often blamed for consumers consumption behaviours as a result of their ineffective marketing. However, consumers have access to the resources and platforms provided by industry associations and MSIs to educate themselves yet choose not to.

In reality, the network is evidently too interconnected and complex for a single actor or a group of actors to bring about real change. Therefore, the real problem lies in the systemic barrier, where a lack of commitment and collaboration arises from the lack of genuine interest in reducing the impact of textile processing. To facilitate GC adoption, there needs to be a systemic cultural shift, in which all actors accept responsibility of their roles and work collaboratively, bringing their strengths to the forefront. Only with shared responsibility and a clear objective, can small but meaningful steps lead to impactful change.

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10. APPENDIX

Appendix I: Interview Guide

Introduction to interview

Hello, my name is Luciana Frosi-Carvalho, I am an Innovation analyst at Fashion for Good while also carrying out my thesis in Sustainable Business and Innovation. My research focuses on exploring how GC adoption can be facilitated in India's textile processing. To do this, I will identify the barriers, map out the actors that are involved within India's processing network, identify their roles and interactions, and then provide recommendation to collectively facilitate the adoption of GC.

I have invited you to participate in the study as

1. an individual with experience and knowledge on the industry
2. As a X, you are an actor who has influence on the adoption process.

Before we start, I want to confirm that you signed the consent form and understood the conditions:

1. The interview will be recorded and transcribed so that an analysis can be carried out.
2. Your name will remain confidential, but your actor type (i.e., manufacturer, innovator) may be mentioned.

Part 1: Participant introduction and problem definition

1. Please introduce yourself and your role at _____?
2. What is the current norm and practices that ____ has built in to make sure they use lower impact chemicals?
3. What are the primary motivations driving ____ to explore and adopt GC?
4. What is your opinion on the current state of GC adoption, within India's textile processing?

Part 2: Actor roles and interactions

2. Who do you typically interact with other actors within the industry?
3. What roles does ____ have on the adoption of GC? How does that influence GC adoption?
4. What actor do you think has the most influence on GC adoption? Why?
5. Have you observed any notable trends or shifts among consumers towards sustainable products and practices, and how does this influence GC adoption?
6. What is your opinion on the role of education in GC adoption? Who are the people that should be carrying out this education?

Part 3: Barriers and solutions

A: Barriers

1. What are the main barriers to GC adoption?
2. What actors have you encountered most resistance or challenges with?
3. Have you faced any challenges with____ (e.g., certifications)?
4. Are there cultural or mindset shifts that need to occur to facilitate greater acceptance and adoption of GC?

B: Solutions

5. **For each barrier:** What solutions have you/can be implemented to address this?
6. How have you personally addressed this barrier?
7. Can you give me examples of the type of tools or strategies that can help incentivise GC adoption?

Part 4: Characteristics of GC

1. Relative advantage
   - What do you think is the relative advantage of GC?
   - What are the added values a GC should hold to be adopted?
   - Can you provide an example of the added value observed from a GC you have adopted?
2. Compatibility
   - How important is it for you for GC to be compatible with current processes/machinery?
3. Complexity
   - Do you find GCs easy or complex to adopt? Why?
4. Trialability
   - Is there a value of conducting trials on GC? Why?

End of Interview

- Thank you for your time, you have given me lots of valuable information. Do you have any questions you would like to ask me?
- Do you have recommendations of people who may be interested in participating that you could put me in contact with? (or ask for specific contacts).
- Please feel free to contact me if you have any further questions down the line and we will keep in touch.

Appendix II: Table of actors identified

The table resembles the table made on excel with the human and non-human actors identified throughout the study. The source and actor types are also listed. The rows colored in Orange are those initially identified during the desk research. The rows in Green are those identified during the interviews.

Actor	Source	Actor Type
Green Chemistry	FFG Internal Search	Non-human
Manufacturer	FFG Internal Search	Human
Innovator	FFG Internal Search	Human
Legislation	FFG Internal Search	Non-human
Restricted Substances List	Internet Search	Non-human
Regulatory Body	FFG Internal Search	Human
Industry Association	FFG Internal Search	Human
Brand	FFG Internal Search	Human
Consumer	Internet Search	Human
Academic Institution	Internet Search	Human
Service-based Provider	FFG Internal Search	Human
Consultant	FFG Internal Search	Human
Certification	FFG Internal Search	Non-human
Trials	FFG Internal Search	Non-human
Life Cycle Assessment	FFG Internal Search	Non-human
Multi-stakeholder Initiative	FFG Internal Search	Human
Machinery	FFG Internal Search	Non-human
Best Practice Guidelines	Interviews	Non-human
Fiscal Incentive	Interviews	Non-human

Appendix III: Desk Research Excel Document

Provided below is the link to the excel document used to map the actor types and the respective examples. Each Table provides the process used and the reason for inclusion of each example.

Link: Excel Thesis Desk Research

Appendix IV: NVivo Project: Final Themes

Screenshots of the final themes that were created via the axial coding on Nvivo during the analysis.

Appendix V: Miro Boards

Provided below is the link to the Miro Boards used to create boards to visualise the best way to group the data into themes during *analysis for sub-question 1 (purple), sub-question 3 (blue), and the main research question (red). Additionally, the Miro boards consist of the figures made for the study.*

Link: https://miro.com/app/board/uXjVKbucRTs=/?share_link_id=574951087782

Appendix VI: Consent form

INFORMATION SHEET AND INFORMED CONSENT FORM

Introduction

The purpose of the study is to learn about the barriers of green chemistry adoption in India's textile processing, and how they can be overcome to facilitate green chemistry adoption. To do this, the actors that are involved within India's processing network will be mapped out, along with their roles and interactions. By understanding these dynamics, the study seeks to provide insightful recommendations for addressing specific aspects of the current network that requires changing in order to gain interest of these actors. Ultimately, the goal is to advocate for adoption of green chemistry, steering away from existing high impact processing chemicals. The study is conducted by Luciana Frosi-Carvalho a student in the MSc programme Sustainable Business and Innovation at Utrecht University, and an Innovation Analyst at Fashion for Good. The study is supervised by Bonno Pel from Utrecht University.

Participation

Your participation in this interview is completely voluntary. You can quit at any time without providing any reason and without any penalty. However, your contribution to the study is very valuable and your time is greatly appreciated. The interview is estimated to take approximately 60 minutes. The questions will be read out to you by the interviewer (Luciana). Some of the questions require little time to complete, while other questions might need more careful consideration. Please feel free to skip questions you do not feel comfortable answering. You can also ask the interviewer to clarify or explain questions you find unclear before providing an answer. Your answers will be noted by the interviewer in an answer template. The data you provide will be used for writing a Master thesis report and may be used for other scientific purposes such as a publication in a scientific journal or presentation at academic conferences. Only patterns in the data will be reported through these outlets. Your individual responses will not be presented or published.

Data protection

The interview is recorded for transcription purposes. The recordings will be available to the Master student and academic supervisors. They will be deleted when data collection is finalised, and all interviews have been transcribed. The data will be processed confidentially and anonymously in accordance with data protection legislation (the General Data Protection Regulation and Personal Data Act). This means that we will not ask for your name, date of birth, or other personal information that can be traced to you by us or a third party].

I confirm that:

- I am satisfied with the received information about the research.
- I have no further questions about the research at this moment.
- I had the opportunity to think carefully about participating in the study.
- I will give an honest answer to the questions asked.

I agree that:

- the data to be collected will be obtained and stored for scientific purposes.
- the collected, completely anonymous, research data can be shared and re-used by scientists to answer other research questions.

I understand that:

- I have the right to see the research report afterwards.

Do you agree to participate? o Yes o No