The decarbonization of supply chains is vital in the fight against climate change (Krabbe et al., 2015; Wade and Rekker, 2020; Hopkins, 2010; Kim and Lyon, 2011; Weinhofer and Busch, 2012). Supply chain's greenhouse gas (GHG) emissions often outweigh emissions of direct operations (Plambeck, 2012; Farsan et al., 2018) – for example, the supply chains of European companies create up to six times more greenhouse gas emissions than their direct emissions (CDP, 2022). As companies are accountable for the accumulated and interrelated sources of emissions embedded in the products and services they offer (Van Hoek et al., 2019), it becomes crucial to develop new forms of managing emissions across supply chains (Jira and Toffel, 2013; Farsan et al., 2018; Ghadge et al., 2020).

A supply chain is a complex system of customers, firms, and suppliers involved in various processes including design, retail, procurement, storage, manufacturing, and shipping (Melkonyan and Krumme, 2019; Ghadge et al., 2020) A dynamic systems approach can, therefore, contextualize supply chain strategies within a complex system, for example by unpacking key stakeholders, their interdependencies, and the emergent behaviors that arise from their interactions (Akkermans and Dellaert, 2005; Rebs et al., 2019; Ghadge et al., 2020; Bueno-Solano and Cedillo-Campos 2014; Scheibe and Blackhurst 2018).

Scholars have extensively investigated corporate responses to climate-related risks and opportunities in supply chain management as reported by single companies or across sectors (e.g. Busch et al, 2022; Caro et al, 2013; Lee and Klaasen, 2015); however, limited research examines the complexity of supply chain management in response to climate change through a system dynamics lens. Previous research has pointed out the benefits of systems thinking and systems dynamics in analyzing sustainable supply chain management (Rebs et al., 2019) but no empirical research so far has applied SD to explore the complexity of supply chain management responses to climate risks. Through the lenses of dynamic systems, we address

the following question: *How do manufacturers in Europe respond to climate change risks and opportunities through their supply chain management strategy?*

In seeking to answer this question, we analyzed the voluntary disclosures of 1095 EU firms as reported through the Carbon Disclosure Project (CDP). The CDP operates a global disclosure system for companies, investors, and regions to manage their risks and opportunities related to climate change, water security, and deforestation (CDP, 2022). We conducted a cross-sectional, multi-case analysis approach to analyze and interpret the data. All reporting manufacturing firms within the EU were included in the dataset to ensure the analysis of a diverse range of responses.

Manufacturing firms were selected because the sector and its supply chains play a critical role in achieving science-based carbon emission reduction goals and scholars have pointed out that climate-related responses of manufacturers are understudied when compared to other sectors (Cadez and Czerny, 2016; An et al., 2021). We chose manufacturers based in the EU for two reasons. First, because the region has one of the most advanced regulatory environments in terms of climate policy (Cadez and Czerny, 2016) – in June 2021, the EU adopted a European Climate Law, establishing the aim of reaching net-zero greenhouse gas emissions in the EU by 2050 (European Commission, 2020). Second, because companies in Europe have a significant environmental footprint and are central nodes in global supply chains that account for up to six times more than their direct GHG emissions (CDP, 2022a).

We started with the compilation of data from all European manufacturing companies that had a CDP report in 2021. We focused on the textual responses to the CDP's report question C3.3: "Describe where and how climate-related risks and opportunities have influenced your strategy?" We analyzed the content of our data with the assistance of NVivo software through the coding of relevant extracts and the identification of patterns and themes across the 1095 companies in our sample (Weber, 1990; Elo and Kyngas, 2007). We then deployed the Gioia

et al.'s (2013) to inductively interpret our coded data and synthesize them into more aggregate themes. Our data analysis revealed sixty-two first-order codes grouped into twenty-one second-order categories and, subsequently, into finally six aggregate themes which represent core supply chain responses to climate change risks.

The six supply chain efforts are: 1) diagnosis of climate-related risks; 2) collaboration with suppliers for emission reduction; 3) adoption of energy reduction and related sustainability strategies; 4) adoption of sustainability practices for waste minimization; 5) enablers of sustainable behaviors and practices; 6) supply chain network redesign. We demonstrate what each response consists of; the efforts they entail and how companies have integrated these different responses into their supply chain management strategies.

As we juxtapose our findings with extant literature we identified two core contributions. First, the literature on sustainable supply chain management, carbon management, and supply chain risk management to date focused on the drivers of sustainable strategy and the categorization of risk responses and sustainability strategies into internal and external, bridging and buffering, and reactive and proactive. Our study contributes to this literature as we identified numerous and wide-ranging risk strategies deployed by EU firms which can be viewed within a larger supply chain system rather than as static, standalone strategies implemented by focal firms. Second, as we reflect on our findings through the lenses of system dynamics, we offer a causal loop diagram that sheds light on the complexity of supply chain management efforts to address climate change. As depicted in Figure 1, supply chain responses to climate-related risks are connected through a series of positive and negative feedback loops. This diagram supports supply chain managers in assessing the anticipated effect of their supply chain strategy on the wider system in which they are situated.

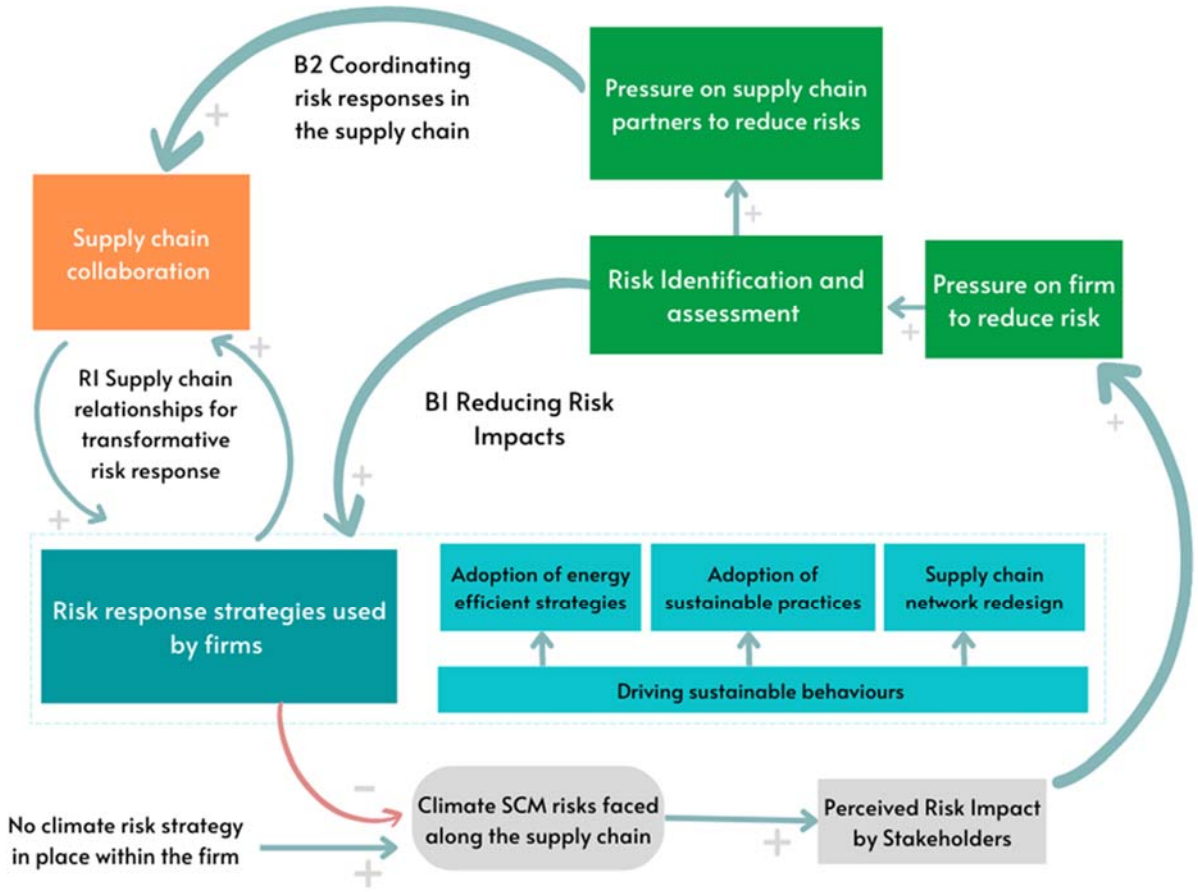

Figure 1: Causal Loop Diagram of Supply Chain Climate Change Risk Management

Our study opens many opportunities for future research. As we only analyzed manufacturing companies in the European Union, future studies can identify how supply chain responses vary across regions and sectors, and whether our causal loop diagram is applicable in those cases too. We also encourage future research to investigate how supply chain responses to climate-related risks have changed over time, as companies become more committed to reducing their carbon emissions.