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Charting the path toward a greener world: A review of facilitating and inhibiting factors for carbon neutrality

Shalini Talwar [a], Amandeep Dhir [b,c,d,*], Adeel Luqman [e], Jaya Gupta [f], Ritika Gugnani [g]

[a] S P Jain Institute of Management & Research, Mumbai, India
[b] Department of Management, School of Business & Law, University of Agder, Kristiansand, Norway
[c] Norwegian School of Hotel Management, Faculty of Social Sciences, Stavanger, Norway
[d] Optentia Research Focus Area, North-West University, Vanderbijlpark, South Africa
[e] College of Management, Research Institute of Business Analytics and Supply Chain Management, Shenzhen University, Shenzhen, 518060, China
[f] Birla Institute of Management Technology, Greater Noida, India
[g] Jaipuria Institute of Management, Noida, India

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ABSTRACT

The carbon neutrality (CN) literature has witnessed a mushrooming growth but also limited attempts to systematize the mass of evidence running in multiple directions. The consequent accumulation of fragmented insights can confuse concerned stakeholders, causing them to neglect or miss crucial discussions. Our study addresses this concern by undertaking a systematic literature review (SLR) of congruent studies to delineate the facilitating and inhibiting factors that support or impede the efficacious achievement of CN targets. Given the vastness of the extant literature, we limited our review to five sectors: manufacturing, energy, transportation, agriculture, and construction (METAC), since these are known to be among the highest contributors to emissions. Using a rigorous search and filtration protocol, we shortlisted 149 studies for inclusion in the review. Going beyond the curation of insights and identifying research gaps to suggest potential research questions for future investigations, our SLR contributes significantly by synthesizing facilitators and inhibitors from the reported evidence. At the same time, identifying stimulating forces and impeding hurdles helped us highlight areas requiring policy attention and managerial action to support the achievement of CN targets.

1. Introduction

Carbon dioxide (CO_2) and other gases emitted during commercial activities have triggered a wave of climate change, which has become a key global concern (A, Zhang et al., 2023; Shao et al., 2023). The rising climate risk has led to the mainstreaming of several measures to control climate change (Jia, 2023). Of the multiple approaches discussed and deployed for mitigating climate risk, sequestering carbon and offsetting emissions have been at the forefront (Cong et al., 2023), emphasizing the goal of achieving carbon neutrality (CN). Aimed at reducing carbon black, CN represents a state of net-zero CO_2 emissions or offsetting emissions through approaches such as carbon sinks, capture, storage, and utilization (Kang et al., 2021; C. Zou et al., 2021). CN is considered an imperative for ensuring sustainable development in the future (Y. Chen et al., 2023; T. Li et al., 2023). Taking note of the seriousness of the climate change issue, scholars and several reports have underscored the need to achieve CN by 2050 (Fabre et al., 2023; Williams et al., 2021).

From the regulatory perspective, governments across the globe have expressed their willingness and commitment to reduce emissions (Van Coppenolle et al., 2023; A. Zhang et al., 2023). In fact, in conjunction with the Paris Agreement in 2015, many countries worldwide have made specific commitments to achieve CN by 2030. Recently many firms have also committed to pursuing net zero emission targets (Berger-Schmitz et al., 2023). In keeping pace with the regulators and businesses, scholars have also discussed ways and means to achieve CN targets at both national and firm levels. For example, L. Cao et al. (2023) discussed the role of digital technologies in supporting the net-zero energy transition, and Sammarchi et al. (2023) examined the implementation of carbon capture technologies for decarbonizing coal-fired power plants. Many other studies have discussed varied emission

* Corresponding author. Department of Management, School of Business & Law, University of Agder, Kristiansand, Norway.
E-mail addresses: shalini.talwar@spjimr.org (S. Talwar), amandeep.dhir@uia.no (A. Dhir), adeel@ustc.edu.cn (A. Luqman), jaya.gupta@bimtech.ac.in (J. Gupta), ritika.gugnani@jaipuria.ac.in (R. Gugnani).

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reduction/CN measures, such as the development of forest carbon sinks (Zhao et al., 2023), sustainable infrastructure (Y. Liu et al., 2022), carbon removal and solar geoengineering (Sovacool et al., 2023), technological innovation (Su et al., 2023), and energy efficiency enhancement (L. Cao et al., 2023).

Despite the initiatives taken by regulators and inputs generated by researchers, the reduction in CO_2 emissions so far has not been enough to allow countries to achieve their CN targets. The shortfall has been documented in the *Emissions Gap Report* (United Nations Environment Programme, 2022), which observed that even after the updated national pledges in COP26 in 2021, we are nowhere near the emission targets required to achieve the Paris Agreement goal. The COVID-19 pandemic has also negatively impacted the efforts of governments and businesses to achieve their net-zero targets (P. Liu, 2023; J. Wang et al., 2023). Scholars observe that the pandemic has had a severe economic impact (e.g., Abbass et al., 2022), which has undermined the ability of governments to pursue their CN targets, particularly in developing and underdeveloped countries. At the business level also, recent studies have noted that commercial activities continue to be significant contributors to emissions (e.g., Leal Filho et al., 2022). In addition, transitioning to a low-carbon state has brought new challenges spread across technologies, actors, and complex discourses (Ohlendorf et al., 2023). Overall, existing scholarship has presented a vivid picture of future challenges in achieving CN targets in a setting characterized by more pledges and increasingly ambitious target setting (Chew et al., 2023; Christiansen et al., 2023).

Considering the shortfalls in achieving CN targets on the one hand and the complexities associated with transitioning to CN on the other, it would be fair to say that despite all their merits, existing CN actions have certain limitations that need to be addressed and overcome. Taking into consideration the present state of CN target achievement and the issues raised by scholars for the future, we argue that (a) understanding different temporal trajectories of success/failure in achieving CN targets, (b) identifying fissures in strategic positioning, (c) discerning between tangential narratives versus overlapping discourses on CN, and (d) uncovering incompatibility in policy design are essential to the achievement of various CN initiatives being implemented by governments and businesses the world over. Moreover, a deep diagnosis of the factors that could lead businesses to dynamically pursue CN or remain stoically static in changing their carbon position is essential to create a conducive environment for promoting CN, such that all socio-technical systems make the required transition (Andersen and Geels, 2023). Furthermore, in alignment with recent research (e.g., Haas et al., 2023; Xiang et al., 2023), we contend that fully mapping and understanding the path dependencies and opportunities that coexist with issues in pursuit of CN targets is crucial for introducing the right strategic initiatives at both regulatory and business levels.

Building on our position, we assert that an effective way to evolve a more valuable and future-oriented discourse on the pathways to achieve CN targets is to (a) gain clarity about the facilitating and inhibiting factors that have stimulated or impeded the pursuit of CN so far, and (b) encourage incisive research in the area by alerting scholars to vital concerns and critical imperatives. As a result, our proposed review the congruent literature aims to delineate the facilitators and inhibitors on the one hand and consolidate the past findings to create a point of reference for future research on the other. Of the several approaches that can be used for reviewing past research, such as narrative review (Andersen and Geels, 2023), we propose to employ the systematic literature review (SLR) approach since it has been effectively deployed by existing scholarship to create a sound consolidation of the amassed knowledge in different contexts such as e-governance (Abuljadail et al., 2023), food waste (Dhir et al., 2020; Kaur et al., 2021), digital innovation (Bamel et al., 2023), big data (Talwar et al., 2021), and the circular economy (Suchek et al., 2021).

Scholars further note that the SLR method derives its merit from its transparent and replicable methodology, which minimizes bias and maintains scientific rigor by providing a robust framework for identifying congruent studies (e.g., Kaur et al., 2021; Talwar et al., 2023). Past studies also prove that the SLR method's value lies in its inherent nature, which goes beyond the quantitative and qualitative synthesis of the relevant literature to support future research agenda-setting (e.g., Bamel et al., 2023). Succinctly, our choice of the SLR approach is guided by its versatility in consolidating fragmented evidence from diverse studies to uncover patterns, trends, consistencies, and knowledge gaps, thus providing a comprehensive illustration of the topic at hand.

Although several attempts have been made to review the literature on CN in the past, our review makes a novel addition to the literature by offering broader insights. In comparison, past reviews have either remained limited to a particular aspect or have focused less on the fine-grained implementational details, thereby restricting the takeaways for multiple stakeholders seeking to achieve CN targets. For instance, Otto et al. (2023) discussed the trust–participation nexus in the context of decarbonization technologies, and Haldar et al. (2023) reviewed energy transition literature in the Indian context. In another review with a specific focus, Gössling et al. (2023) evaluated the scales, scopes, stakeholders, and carbon management strategies in the tourism sector. Other recent reviews include analyses of the co-benefits associated with energy demand reduction (Finn and Brockway, 2023), the role of natural gas in industrial decarbonization (Mathur et al., 2022), decarbonization of energy-intensive industries and the efforts made to restrict climate change (Nurdiawati and Urban, 2021), and new CN technologies (F. Wang et al., 2021). In a similar vein, other scholars have reviewed pathways to low-carbon energy transitions (Abbass et al., 2022; Carvalho et al., 2021).

Compared to previous attempts to review the CN literature, our SLR provides more comprehensive insights by delineating the facilitators and inhibitors that have supported or hindered progress toward the timely achievement of CN targets. Explicitly, we seek to address four research questions (RQs) to articulate our orientation and objectives: **RQ1**. Which factors stimulate, support, and motivate firms to adopt and implement practices that can expedite the achievement of CN targets? **RQ2.** Which factors impede, inhibit, and obstruct firms from adopting and implementing practices that can expedite the achievement of CN targets? **RQ3.** How do these facilitating and inhibiting factors differ from sector to sector? **RQ4.** What are the gaps in the extant research, and how can these be addressed?

Since CN is a vast area of study with scholarly work from various disciplines and perspectives, we specified the conceptual boundary of our study by setting two conditions: (a) shortlisting a relevant set of studies from pre-specified subject areas and (b) focusing on five key sectors—manufacturing, energy, transportation, agriculture, and construction (METAC)—based on ongoing discussions about their high emissions.

The significant contribution of our SLR can be summed up as follows: First, it maps the facilitating and inhibiting factors that promote or inhibit the efforts to achieve CN targets by synthesizing evidence and insights that do not apparently identify or list these factors. Second, our study not only offers a new perspective on the current understanding of factors that can support or impede CN implementation but also opens new research streams by offering a detailed and fine-grained discussion of research gaps, contextualized through reference to the METAC sectors. Thus, in reviewing a large corpus of documents, this SLR contributes to clarifying various aspects of CN, which continues to be a challenging area with multiple nuances and incongruities that need to be better understood.

2. Method

The current study aims to review the extant literature on CN using the SLR approach. This approach is useful for synthesizing, consolidating, critically evaluating, and reproducing principal findings of amassed research in a particular domain. Moreover, an SLR enables robust and comprehensive inclusion of congruent literature following rigorous protocols and processes leading to a systematic analysis and report of the extant findings (Talwar et al., 2020).

Since the quality of an SLR is largely dependent on (a) the studies included in the review and (b) the robustness of content analysis, we adhered to prescribed protocols to ensure both. For identifying congruent studies, we utilized the established criteria and tools specific to SLRs. Apart from diligently selecting keywords for the literature search, we also determined specific inclusion and exclusion criteria, keeping in mind the amorphous nature of CN and the multitude of dimensions it embodies.

To avoid any risk of bias at the shortlisting and content analysis stages, two authors independently coded the data, meeting frequently in the presence of all authors to discuss and resolve any differences. At the same time, we sought the input of experts to determine the final set of studies to be included in the review. To ensure the quality of selection and remain in alignment with prior studies, we undertook a thorough examination of the preliminary shortlist in terms of methodological aspects such as study design, sample size, data collection methods, and data analysis techniques (e.g. Higgins, 2011).

Adhering to a distinct and sequential approach employed in prior studies (Dhir et al., 2020; Madanaguli et al., 2021), we followed five steps to execute the SLR (see Fig. 1).

The five steps are (i) Specification of research questions, (ii) Specification of search protocol, (iii) Data extraction, (iv) Content analysis and discussion, and (v) Identification of gaps and setting future research agenda. The first three steps are aimed at assembling and arranging the data for review, and the last two steps involve assessment.

To begin with, based on the need for further research on CN and the gaps in the findings offered by existing reviews, we identified four specific research questions to focus our review. These questions, presented in the preceding part, set the conceptual boundary of our study and guide its execution. Next, we specified the study search protocol so that the most relevant studies could be obtained to address the identified research questions. The specification of pertinent keywords is the first step in this direction. Since our focus is on specifically examining CN, we determined '*carbon neutrality*' and '*carbon neutral*'' as keywords and searched them on two key digital databases, Web of Science (WoS) and Scopus, as these are recognized to be exhaustive and comprehensive (Mongeon and Paul-Hus, 2015).

To identify the studies relevant to the scope and objective of our review, we defined three inclusion criteria: (i) peer-reviewed journal articles, (iii) articles published in English, and (iv) articles on subject areas related to business management, social sciences, economics, decision science, arts, psychology, or multidisciplinary fields. Conversely, we set the following exclusion criteria: (i) conference proceedings, working papers, periodicals, reports, editorials, thesis, dissertation, and book chapters, (ii) studies focusing on subject areas related to pure sciences, and (iii) duplicate studies with same DOI. Herein, we began by including all articles that complied with the specified inclusion criteria.

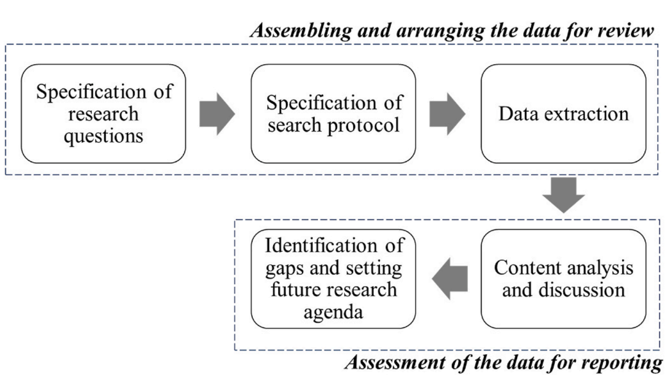

Fig. 1. The SLR process.

After that, we applied the exclusion criteria to remove the articles not in congruence with our study's objectives and research questions.

After executing the initial search in November 2021, using the search string "carbon neutral*," we found 4486 document results from Scopus and 3131 results from the Web of Science (WoS) core collection. Such a large number of studies is not surprising since carbon neutrality is a topic that has vast appeal in different disciplines ranging from arts to medicine. However, guided by our study's conceptual boundary and objective, we were interested in only pre-specified subject areas, excluding such disciplines as chemistry, physics, biology, mathematics, medicine, immunology, pharmacology, veterinary medicine, and geology. As a result, we applied our pre-specified inclusion and exclusion criteria to arrive at a more pertinent set of studies. We were left with 1762 document results from Scopus and 1888 results from WoS. Taking the next step toward the filtration of congruent studies, we amalgamated these results and eliminated the duplicate records to arrive at a joint pool of 2631 unique studies. The joint pool comprised 743 records indexed in Scopus and 1888 in WoS.

At this stage, two authors independently undertook the task of reading all abstracts to cull the ones that were incongruous with our pre-specified subject areas or veered into pure sciences domains. Subsequently, all authors met to discuss the joint shortlist so generated. After some discussion, the author team reached a consensus on the final list of 289 studies to be taken forward for full paper reading. At this stage, we invited two method experts to review and cross-check the shortlist. They suggested some corrections, resulting in the elimination of 16 studies.

Next, two authors independently read the full texts of the 273 shortlisted studies to further filter them for relevance, going beyond an overarching reference to CN. Following the same process as described above, we identified a set of 130 studies to be potentially included in the review. At this stage, we invited two experts (different than method experts) to vet this set. They made some suggestions on the exclusion of 13 studies, which were not relevant for inclusion in the SLR since they offered no sector-specific insights. At the same time, given their expertise and familiarity with the field, they also suggested the inclusion of some studies that were not on the shortlist. Following their inputs, we updated our set for consideration to generate a list of 119 studies in the review. As a further step to ensure the inclusion of congruent studies that were not indexed in Scopus or WoS, we undertook backward chaining to mine the list of references of these studies for additional records. We also undertook forward chaining to filter the studies that have cited studies in our shortlist. This resulted in an additional set of 30 studies.

At the end of this multi-phase shortlisting process, we had a set of 149 studies for inclusion in the review.

3. Research profiling

To begin with, we compiled basic descriptive statistics of the shortlisted papers. The research on CN is increasing at a rapid pace, with scientific production almost doubling each preceding year. In terms of sectoral distribution across METAC, the final data set of 149 studies was divided as follows: manufacturing (28), energy (52), transportation (24), agriculture (21), and construction (24).

An exploration of the geographic scope of the selected studies highlighted the spread and coverage of CN research across different countries: China (n = 35), Finland (n = 9), USA & UK each (n = 8), Australia and Germany each (n = 7), Italy (n = 6), Denmark, France, India and Spain each (n = 5), Japan and Netherlands (n = 4), Belgium, Brazil, Korea, Portugal, and Singapore each (n = 3), Canada, Chile, Croatia, Latvia, and Sweden each (n = 2), Czech Republic, Ghana, Greece, Indonesia, Iran, Ireland, Malaysia, New Zealand, Poland, Qatar, Saudi Arabia, Slovenia, Switzerland, Taiwan ROC, Turkey, and UAE each (n = 1).

4. Thematic Foci

The objective of our study was to delineate facilitators and inhibitors that have supported or impeded the implementation/adoption of CN practices in METAC industries. To this end, we undertook an in-depth content analysis of the generated corpus of congruent studies, as described in the preceding part. Accordingly, two members of the author team independently coded the shortlisted studies to understand and extract the key discussions, which then served as the basis for populating the set of facilitators and inhibitors. Since each industry sector is unique, with its own emission trajectory and challenges, the coding team also classified the delineated barriers under the heads of five sectors.

We resolved the inter-coder discrepancies, albeit limited, through discussions and arbitration with other members of the author team. As in the case of shortlisting congruent studies, we invited two experts to review the overall classification of the factors into facilitators and inhibitors. For clarity of narrative and sharpness of presentation, we followed the conventional approach of thematic classification, dividing the underlying text into five themes, each representing a sector of METAC. Each of these was bifurcated into two sub-themes—facilitators and inhibitors—which were further stratified into distinct categories, as presented in Fig. 2 and discussed below.

4.1. Manufacturing

4.1.1. Manufacturing: facilitators

A review of the literature revealed that the shortlisted studies on corporate CN have primarily explored three key aspects that can be categorized as facilitators of better environmental practices: (i) input material substitution, (ii) breakthrough technologies such as additive manufacturing, and (iii) remanufacturing/recycling.

(i) *Input material substitution*: Pioneering literature has shown that input material substitution significantly improves energy efficiency and reduces emissions. For example, Oliveira et al. (2015) proposed cogeneration and suggested that replacing biomass with natural gas in electric arc furnaces (EAF) in the steel-making industry can significantly reduce emissions. Continuing the focus on steel-making, Choi et al. (2016) suggested that South Korea and China should increase CO_2-absorbing trees, such as fast-growing bamboo trees, to be used as a source of CN charcoal for coal injection in the steel-making processes. Discussing the cement sector, Schakel et al. (2018) suggested that switching from carbon-intensive fuels to low-carbon fuels, such as biomass and natural gas, could reduce fuel combustion emissions by about 54%. For the same sector, Lim et al. (2018) observed that a positive emission reduction action can be initiated by using agricultural waste such as oil fuel ash and rice husk ash to produce nano-cementitious additives that increase the strength of Portland cement. Giving more specific inputs, Lin et al. (2021) established through a carbonation experiment that replacing belite-rich cement with 20% quartz and limestone could stimulate carbonation. W. Liu et al. (2021) discussed energy conservation and emissions reduction in the manufacture of aluminum alloy used predominantly for in the automotive industry. The study revealed that the energy consumption in the manufacture of structural die cast, which is used more frequently, was higher than box-type die cast. The study suggested that high-vacuum and semi-solid die casts should be considered as more energy-saving alternatives.

In sum, the shortlisted studies examining input material substitution as a way to reduce emissions and initiate a positive climate change countermeasure focused on the most polluting manufacturing subsectors, including steel and cement making.

(ii) *Breakthrough technologies such as additive manufacturing*: Scholars have suggested that the CN targets that countries and firms have committed to achieving by 2050 require a substantial overhaul of production processes and the implementation of breakthrough technologies. For example, Sanjuán et al. (2020) observed the European Green Deal CN target could be achieved by changing cement production processes and clinker-to-cement ratios. The study also suggested the adoption of novel technologies such as carbon dioxide capture, utilization, and storage for achieving CN. Similarly, other studies included in our review have also suggested various changes in the production process that can help reduce gaseous emissions and achieve CN targets.

Q. Lu et al. (2021) contended that using a single chemical

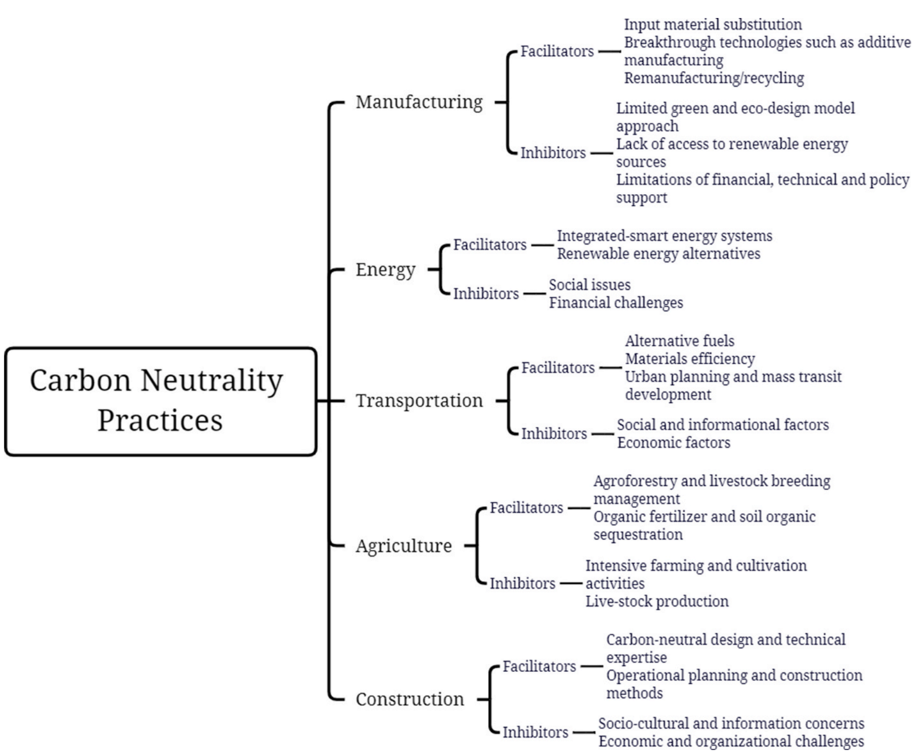

Fig. 2. Overview of themes.

composition to produce multiple steel grades for the entire lightweight automotive body-in-white can simplify the welding process, reduce energy consumption, and contribute to CN. In a study comparing the additive and subtractive metal parts production and supply chains, Rupp et al. (2022) suggested that the digital spare parts approach resulted in lower emissions. To summarize, the reviewed studies examining the impact of the implementation of breakthrough technologies suggested that these were more often than not effective facilitators of efforts to enhance CN.

(iii) *Remanufacturing/recycling*: Remanufacturing entails rebuilding a product as per the specifications of an original manufactured product by using a mix of reused, repaired, and new parts, which is a practice being adopted by firms to align with the Extended Producer Responsibility (EPR) legislation requirement (Johnson and McCarthy, 2014). B. Li et al. (2021) contended that authorized remanufacturing was a significant and effective way to achieve CN targets. Studies included in our review bring forth the growing evidence that remanufacturing industrial products is a potentially effective solution for saving pure energy and reducing emissions. For example, there is evidence that the carbonation of concrete waste and concrete blocks for construction products or other uses reduces emissions (Lippiatt et al., 2020). Discussing cement production, Quéheille et al. (2021) argued that the mineralization of nickel slag to produce silico-magnesian cement can significantly reduce emissions.

Focusing on the less-discussed textile sector in this regard, Semba et al. (2020) proposed ways of reusing and recycling used clothes, such as textile recycling to make wipers, fiber recycling, chemical recycling, and thermal recycling, as an approach to reduce emissions since it would discourage virgin clothing manufacturing. In another study of the same sector, conducting a textile life cycle assessment, Payet (2021) noted the sector's high greenhouse gas (GHG) emissions and carbon footprint and suggested that proper recycling of unsold clothing and eco-design approaches could be effective in reducing emissions. Putting life cycle assessment to practical use, Tang et al. (2023) suggested that since aluminum smelting and carbon anode consumption were the most CO_2-emitting processes, replacing primary aluminum with secondary aluminum could help reduce emissions substantially. In a study discussing CN targets, Barecka et al. (2021) demonstrated the economic viability of CO_2 electro-conversion as a chemical feedstock for petrochemical plant bulk products and suggested that retrofit-based on-site CO_2 recovery could contribute up to 50% of the industrial CN target. Putting it succinctly, the reviewed studies establish remanufacturing as a viable approach to support the achievement of CN targets.

4.1.2. Manufacturing: inhibitors

A review of the shortlisted studies indicated that the existing scholarship considered certain factors as hindrances to firms' efforts to pursue CN and achieve the related milestones. Taking the overarching related discussion, we suggest three key inhibitors that can potentially obstruct the industrial sector in its efforts to achieve CN targets: (i) a limited green and eco-design model approach, (ii) a lack of access to renewable energy sources, and (iii) limitations in financial, technical, and policy support.

(i) *Limited green and eco-design model approach*: Industrial consumption and production system efficiency drive economic development, but it comes at the cost of the environment. Consequently, scholars take a deep interest in examining ways in which various industrial sectors can grow without compromising the environment. In this regard (Virta and Räisänen, 2021), observed that although green or sustainability issues in the textile sector have gained prominence in the media, policy initiatives driving sustainable production and consumption have not been debated much in the context of textiles. The study notes that a stronger impetus is required in terms of eco-labeling of goods and services, amongst other measures. Continuing with textiles as an example, Payet (2021) found that potential inhibitors to achieving CN goals are the failure to reduce unsold inventory and a lack of well-defined eco-designs. Furthermore, studies such as Benešová et al. (2021) have underscored the importance of Industry 4.0 innovations for sustainability and the competitive advantage of firms while expressing concern that business readiness to implement such innovations is quite low. Drawing upon these findings, it can be said that, as of now, firms have shown limited acceptance of Industry 4.0 innovations, new digital strategies, green protocols, or eco-friendly practices, obstructing the efficacious implementation of CN practices.

(ii) *Lack of access to renewable energy sources*: The industrial sector accounts for 37% of global energy consumption, which is expected to rise further. So far, energy sources in this sector have been the traditional ones, which come with several emission challenges. The replacement of conventional fossil fuel sources with alternative ones can help reduce emissions, yet sufficient renewable energy is not available or accessible to most industrial units. Citing an example, Arens et al. (2021) observed that the lack of availability of renewable electricity for powering global steel production is an issue that can hinder the sector's low-carbon transition as envisaged in the Paris Agreement. Amongst several reasons driving such shortfall in various industries globally is the fact that renewable energy generation and usage have multiple requirements that may not always function together.

Discussing the potential issues impeding the accessibility and use of solar and wind energy, S. Chen (2019) highlighted the need for a spatially specific assessment of the available resources for renewable energy generation. In their study, Bogdanov et al. (2019) argued that despite the fact that available renewable energy sources are sufficient to meet current and future energy demands, the challenge in their usage comes from the stability of some energy systems and societal acceptance. Furthermore, the transition dynamics influencing the deep decarbonization of energy-intensive manufacturing/processing industries, such as iron and steel, chemicals, and cement, is complex and challenging (Wesseling et al., 2017). In sum, several constraints, including the inability to involve all stakeholders to generate and distribute sufficient renewable energy to meet the manufacturing sector's energy needs, can be considered a key inhibitor impeding the desired progress to achieve CN targets.

(iii) *Limitations of financial, technical, and policy* support: CN practices are very complex and require a certain amount of expertise and investment that may be difficult for many firms to arrange. Existing scholarship has noted, either directly or indirectly, that these two factors are indeed one of the primary inhibitors impeding firms' pursuit of their short- and long-term CN targets. In their study on iron and steel production, Fan and Friedmann (2021) assessed the available decarbonization technologies to contend that no single available approach was effective on its own to support deep decarbonization in the industry, despite each having substantial costs attached to it. In another study of iron and steel manufacturing, Mandova et al. (2019) argued that the high implementation cost of bio-carbon capture and storage was a key constraint in the use of clean energy practices. As a result, these studies have called for policy initiatives to provide financial incentives for promoting decarbonization (Fan and Friedmann, 2021; Mandova et al., 2019). In a similar vein, Dolge and Blumberga's (2021) discussion of low-emission intensity industries indicated that financial incentives and subsidies, among other things, can be effective in supporting decarbonization activities. Past studies have also given thought to the financial perspective, suggesting that the manufacturing industry faced a dilemma between economic performance and sustainability (Dolge et al., 2021).

Policy initiatives also play a negative role in increasing costs, as is evident from the carbon emission trading schemes implemented by some countries that exceed environmental regulations, impacting the economic cost structure of industries (Choi et al., 2016). In their study on authorized remanufacturing, B. Li et al. (2021) examined the impact of carbon tax policies and government subsidies to reveal that these policies can adversely impact unit cost, sales, and consumer surplus. In addition to financial impediments, there are some technical impediments in the use of decarbonization approaches, with some being intrinsic, such as the mechanical strength of the material, and others being systemic, such as integration of these systems in the process (Fan and Friedmann, 2021). Existing literature also reports that the industry currently lacks the required in-depth technical knowledge of the different renewable energy sources, which hinders the adoption of many low-carbon technologies. For instance, C. Chen et al. (2019) pointed out that the technical issues related to the intermittency and variability of renewable energy caused fluctuations in its availability and impacted the stability of the grid.

Finally, scholars suggest that permanent emissions reduction requires deliberate and persistent policy support (Belbute and Pereira, 2020), indicating that the current policy imperatives are potentially ineffective and act as a hindrance in the achievement of CN. This sentiment was expressed by Pianta and Lucchese (2020), who called for the formulation of a broad set of industrial policies to address green concerns, along with economic outcomes. In addition, C. Chen et al. (2019) noted that policy directives also posed difficulties in the use of renewable energy, contending that some policies stress energy efficiency, which is an inadequate metric since it overlooks the environmental benefits.

In summary, scholars observe that in their efforts to promote a carbon-free economy and implement climate mitigation practices, countries and industries are facing limitations relating to financial, technical, and policy support. In other words, the extant literature agrees that the lack of financial assessment, resources, and technical expertise acts as an inhibitor since it raises concerns among industrialists that adopting new technologies could increase costs and make them uncompetitive in the market.

4.2. Energy

4.2.1. Energy: facilitators

The studies on CN and the energy sector have discussed various enabling factors, mentioning them upfront or implying them as a part of the main narrative. The discussions were deep enough to help us delineate two key facilitators that can promote and support the implementation of CN practices in the sector: (i) integrated smart energy systems and (ii) renewable energy alternatives.

(i) *Integrated smart energy systems*: This type of system refers to a renewable energy technology mix coupled with storage technologies and integrated with electricity, transportation, and heating systems to achieve a synergistic effect and improved the performance of the overall energy system (Lei et al., 2021; Tan et al., 2021). Scholars have noted the key benefits of smart energy systems in terms of their efficiency (Lei et al., 2021) and cost-effectiveness (Tan et al., 2021). In consonance, other studies, such as the one by Oyewo et al. (2018), observed that 100% renewable energy-based power systems integrated with several storage technologies were competitive energy systems providing the lowest-cost electricity for developing countries.

Some of the studies included in the review have made actionable suggestions for implementing smart energy plans. For instance, Bačeković and Østergaard (2018) proposed a smart energy plan that not only produced 14% extra energy but also had cost parity with the existing system, and Bogdanov et al. (2019) proposed a steady worldwide radical energy transformation plan for achieving 100% renewable energy, which is economically viable and sustainable for achieving CN targets. Similarly, Morvaj et al. (2017) developed integrated distributed energy systems and district heating designs. The study noted that a 100% renewable energy share in such systems significantly impacted the electric grid and offered a potentially effective way of achieving CN targets. Making another reference to heating, Arabzadeh et al. (2019) examined the coupling of heating with variable renewable energy sources at national as well as city levels to show that the practice would not only enhance the flexibility of energy systems but also reduce emissions.

Continuing in the same vein but using an island energy system as context, Dorotić et al. (2019) discussed an optimized system comprising 100% intermittent renewable energy coupled with smart charge vehicles, and Y. Liu et al. (2021) analyzed an interactive energy monitoring system via a non-intrusive scheme to offer an effective smart home solution.

Contending that energy efficiency is an important part of a zero-carbon energy system, Dominković et al. (2016) discussed the transition to a 100% renewable energy system with the assumed sustainable use of biomass. The modeled system was based on the coupling of the smart energy system concept with power-to-heat and power-to-gas technologies. In support, Pfeifer et al. (2021) observed that the energy modeling plan firmly establishes that flexibility is key when the transition to a renewable energy system is 70% or more.

Further examination of the shortlisted studies shows that scholars have also discussed the cost aspect of these systems in detail. For instance, Lei et al. (2021) evaluated uncertainty in energy price movements, proposing a multistage energy hub and network for a regionally integrated energy system, and also determined its feasibility. Van Zuijlen et al. (2019) developed a power system model for Western Europe for 2050, taking technology costs, demand, and generator flexibility into consideration. The study revealed that the optimal cost mix for negative carbon power systems comprised low-carbon capacity, intermittent renewable energy sources, and flexibility capacity. Yuan et al. (2021) undertook an extensive techno-economic analysis to find the optimal district heating strategy based on a hybrid methodology framework that coupled an hourly smart energy system simulation with optimization and decision-making criteria. Finally, F. Li et al. (2021) proposed an optimization model for a regional integrated energy system to minimize the system's total cost.

All in all, it is evident from the preceding discussion that scholars have given extensive attention to integrated smart energy systems by examining potential designs and financial aspects, indicating that these are key facilitators of efforts to achieve CN.

(ii) *Renewable energy alternatives*: Scholars have acknowledged that the use of renewable energy sources reduces emissions (e.g., Hu et al., 2021; Lin et al., 2021), and they have examined various aspects of its use, including remote renewable energy supply chains (Berger et al., 2021). Other shortlisted studies have discussed a variety of renewable energy options, including photovoltaics (PV) and wind energy sources, biofuel, and hybrid energy platforms. Existing scholarship has also emphasized the need to focus on fuel consumption for energy conservation and management (Zeng et al., 2021).

Starting with PV and wind energy, past studies note that these provide direct or virgin energy options that do not need to be converted or stored before use (e.g., Okuyama et al., 2022). Past studies have discussed specific characteristics of these sources and how they can contribute to achieving CN targets. For instance, Gils and Simon (2017) suggested that synthetic hydrogen can help in the integration of intermittent renewable energy power generation. Addressing an oft-debated question, Wu et al. (2021) argued that although solar power is not as renewable as generally perceived, it is certainly a better alternative as compared to coal-fired electricity generation. In support, other studies have noted that solar PV-based electrification of all industrial sectors and buildings would effectively help achieve CN targets (e.g., Middelhauve et al., 2021; Osorio-Aravena et al., 2021). However, presenting a counter view, Okuyama et al. (2022) argued that adopting residential PV would increase emissions rather than reduce them since households with PV ended up consuming more electricity.

Scholars also explored aspects such as solar pumping systems (Bassi, 2018), the spatial distribution of solar radiation and wind energy (S. Chen, 2019), and the use of solar PV, hydropower, and onshore/offshore wind for hydrogen production (Kakoulaki et al., 2021), while discussing ways of reducing emissions.

Some reviewed studies also focused on the implementational aspects and discussed issues such as demand side management for handling electrical load during peak hours (Pluta et al., 2020), the use of renewable sources to reduce costs and overcome load fluctuations from electric vehicle charging (J. C. Gao et al., 2021), and generative models to manage uncertainties associated with weather-based sources such as PV and wind power (Dumas et al., 2022). In addition, Gils et al. (2017) contended that expanding the capacity of wind and solar power is better from a cost perspective as compared to hydroelectric plants. C. Chen et al. (2019) assessed direct and indirect electrification of the methanol production process to show that at around 88% of renewable penetration, CN is achieved in the indirect process.

A limited number of studies included in the review have focused solely on wind energy, but the ones that did offer interesting insights. For instance, based on the assumption that integrating offshore wind with energy storage can help improve wind energy management and reduce the gap between generation and supply, X. Liu et al. (2021) developed a techno-energy-economic assessment model for calculating and comparing economic and system performance indicators. Potrč et al. (2021) assessed renewable energy penetration in Europe and suggested that wind would be a suitable option in the short term, while after 2030, photovoltaics would be more suitable due to cost-effectiveness. Relatedly, C. J. Gao et al. (2021) showed that wind turbines consumed the least energy of various renewable energy sources and had a noticeable positive impact on the environment.

In addition to wind and solar sources, biomass is another renewable energy source that has high accessibility (Raza et al. (2021). Prior literature has discussed various biofuel options to mitigate climate change and achieve CN. For instance, Murillo et al. (2021) noted that a combination of oat husks and pine sawdust was an efficient source for biofuel production, Kuittinen et al. (2021) suggested Salix biomass as a potential feedstock for biofuels, and Singh et al. (2016) proposed enzymatic saccharification and fermentation of rice straw for bioethanol production. García et al. (2020) also supported using bio-ethanol to reduce emissions.

Offering an interesting insight, Mateus et al. (2017) revealed that some cultivations aimed at producing biomass were a preferable supply option since they were carbon neutral throughout their life cycle. At the same time, Walker et al. (2013) raised a word of caution by using a debt-then-dividend framework to show that emission benefits gained from wood biomass energy depend on the forest where they are being generated and the technology employed. Some studies, albeit a small number, have discussed aspects such as a decision-making model for prioritizing geographic provinces to produce renewable energy from cellulosic (biomass) materials (Azizi et al., 2016) and an optimization model for integrating biomass into energy supply chain networks (Murele et al., 2020).

Elaborating on alternative fuel choices, Demirbas (2017) noted that hydrogen fuel can replace fossil fuels as a sustainable renewable energy source if it is produced from biomass, and in a similar discussion on the sustainability of aviation fuel, Goldmann et al. (2018) considered the potential of five electro fuels as more sustainable alternatives to conventional Jet A-1 fuel.

Moving on, past studies have confirmed that electrification and hybrid technologies are efficient pathways to clean energy that can drive the achievement of CN targets. In particular, scholars have called for advances in wastewater treatment, highlighting it as an energy source (Hao et al., 2015; Zhang and Liu, 2022); hybrid PV and wind turbines (S. Cao, 2019); hybrid energy systems with deep water source cooling, biomass heating, and geothermal heat and power (Tian and You, 2019); hybrid generation systems comprising photovoltaics and biofuel generators (Kumar et al., 2020); and integrated energy systems comprised of hydrogen natural gas and hybrid energy storage systems (Tan et al., 2021) for their potential to limit emissions.

Overall, the discussions in the extant literature present a consensus view that using different types of renewable energy alternatives can support efforts to achieve CN. As a result, we have categorized renewable energy alternatives as one of the facilitators of CN in the energy sector.

4.2.2. Energy: inhibitors

Previous literature suggests that despite the known benefits, there are certain factors that obstruct the adoption and implementation of various clean energy alternatives. Analysis of the studies included in the review indicates that the low adoption of clean energy sources could be due to limitations arising from social acceptability and economic issues. As a result, we have listed two types of inhibitors in this context: (i) social issues and (ii) financial challenges.

(i) *Social issues*: The reviewed studies have noted that social issues and the public mindset could obstruct the use of energy sources that are well-acknowledged to limit emissions. For example, Bolwig et al. (2020) analyzed social acceptance across a portfolio of energy system scenarios and observed that a lack of societal interest in large-scale decarbonized electricity increases costs at the consumer level, and Schreyer et al. (2020) cautioned that the lack of social acceptance in the EU is likely to endanger the successful transition to renewable energy sources. Algarvio (2021) underscored the importance of the social aspect by revealing the crucial role played by citizen energy communities in moving toward a carbon-neutral society. Jeong et al. (2021) used a big data analysis to contend that the successful penetration of renewable energy can be ensured by not only knowing and understanding public opinion but also by resolving people's concerns diligently. In another study that underscored the social dimension, Byrne and O'Regan (2016) showed that community-based projects for sustainability transitions were more successful in engaging a larger set of stakeholders as compared to top-down initiatives, which were more likely to fail.

(ii) *Financial challenges*: Since transitioning from traditional energy to renewable and sustainable alternatives comes at a cost, scholars have discussed the existence of financial challenges that can adversely impact the diffusion and adoption of alternative energy sources. For instance, discussing the role of financial measures for renewable energies, Dahal et al. (2017) argued that Helsinki's solar energy subsidy program and fiscal measures were not attractive enough to promote its production or use, causing the efforts to remain in their infancy. In a similar vein, Sun et al. (2021) observed that subsidies were essential for realizing the potential of crop residues to contribute to the energy supply and reduce emissions. Reaffirming the role of finance in promoting cleaner technologies, Qin et al. (2021) argued that executing such projects mandated the existence of a system for financing them as a pre-requisite. Putting forth a different perspective, Lahiani et al. (2021) contended that changes in financial development measures, both positive and negative, impacted the consumption of renewable energy.

4.3. Transportation

4.3.1. Transportation: facilitators

As in the case of manufacturing and energy, the shortlisted studies have acknowledged that the transportation sector has been active in its efforts to limit emissions and achieve CN targets. The discussions and evidence presented in these studies have helped us delineate various factors that have facilitated the process. These facilitators can broadly be grouped under three headings, which are discussed below: (i) alternative fuels, (ii) material efficiency, and (iii) urban planning and mass transit development.

(i) *Alternative fuels*: The studies included in the review and classified within the transportation sector have examined multiple alternative fuel options for surface, air, and sea transportation that can help mitigate climate change and achieve CN targets. Interestingly, Yin et al. (2015) noted that while the immediate potential of the transportation sector to mitigate emissions was lower as compared to the construction and industrial sectors, in the long run, the use of negative-carbon fuel production technologies can enable this sector to contribute significantly to carbon mitigation. The study suggested that biofuel was one of the best fuel alternatives. This finding notwithstanding, there is a lack of consensus in the literature about the use of alternative fuels being an effective approach for achieving CN targets, motivating scholars to explore them further. In a study of surface transport, García et al. (2020) examined and confirmed the potential of bio-ethanol as an alternative to fossil fuels, given its carbon-neutral emissions. Focusing on the important but less-examined alternative jet fuels, Baledon et al. (2022) examined the effect of stakeholders' perceptions on policies and regulations supporting their use. Sharma et al. (2021) also discussed the emissions issue in the aviation sector, suggesting that the use of alternative biofuels can be effective in moving toward CN.

Moving from air to water transport, Carvalho et al. (2021) evaluated various marine fuel options to show that green hydrogen and ammonia were not economically viable but were useful in the long run. A similar sentiment was echoed by Xing et al. (2021), who argued that although zero-carbon synthetic fuels, including hydrogen and ammonia, could play an important role in domestic and short-sea shipping, they were not commercially feasible due to costs and infrastructure. At the same time, the study suggested that methanol was a better alternative fuel option for global shipping transportation.

(ii) *Material efficiency*: In addition to using alternative fuels, scholars have suggested various material and input-related measures that can be considered as facilitators for lowering emissions related to aviation and other types of transportation. Scholars have examined air transport and CN from different perspectives, such as the impact of the CN strategy on the efficiency of airlines (Cui and Li, 2017). Contributing more insights on emissions reduction in the aviation sector, Kılkış et al. (2019) suggested that using lightweight materials to manufacture aircraft can save fuel and reduce energy-based CO_2 emissions significantly. In a similar vein, W. Liu et al. (2021) observed that the use of lightweight high-vacuum/semi-solid die-casting vehicle manufacturing materials can improve energy performance and mitigate emissions. In one of the few studies on railways, Ortega et al. (2018) brought out the sustainability dilemma quite lucidly. Discussing the installation of under sleeper pads during rail track renewal, the study showed that emission savings are low and slow with respect to the economic impacts of such installations. However, the fact remains that using non-recycled rubber for under sleeper pads not only offsets carbon emissions but also reduces track maintenance and renewable needs.

(iii) *Urban planning and mass transit development*: Extant research suggests that urban planning can significantly reduce transport emissions (e.g., Nieuwenhuijsen, 2020). The reduction in energy consumption and emissions is made possible by condensing the distance between offices and residential areas, thereby reducing travel time and enabling the use of public transport and cycling (Ewing and Cervero, 2017). Nevertheless, some scholars have expressed their concerns regarding the compactification of cities, arguing that compact cities can adversely affect citizens' health (Mueller et al., 2021). A counter-argument is also available in the literature, wherein scholars contend that cities can be made healthier by undertaking sound urban and transport planning (Mueller et al., 2021; Nieuwenhuijsen, 2020). This view has found support among various researchers. For instance, Hasan et al. (2019) undertook a qualitative study to propose a public transport policy change to improve ride quality and bus frequency and reduce travel time. The study argued in favor of changing building designs to create urban spaces that are compact and public transit-oriented. Providing a strong argument for public transit, Ku et al. (2021) presented a thought experiment to show the power of public transit investments to catalyze macro-level transformations in not only transportation but also in the power sector. The intrinsic argument of the study was that proper coordination across various energy supply chains could be leveraged to scale up larger efforts to decarbonize transportation and the electric grid. Discussing logistics from a business perspective, some studies included in our review set have particularly noted the efficacy of advanced logistics in improving supply chain efficiency (e.g., Khan et al., 2021).

4.3.2. Transportation: inhibitors

A review of the shortlisted studies mapped to the transportation sector showed that despite the heightened conversation and deep debate around the need for the mass adoption of fuel-efficient vehicles and emission-limiting practices in the entire sector, emission issues persist. Scholars have observed that the positive efforts and initiatives to reduce emissions and decarbonize the sector are often hindered by certain factors acting as barriers. Based on these discussions, we delineated two factors that inhibit the pursuit of CN targets by the sector participants: (i) social and informational factors and (ii) economic factors.

(i) *Social and informational factors*: The literature acknowledges that progress on the CN front, such as the move toward low or zero-emissions public transport, is possible only with the cooperation of a large set of stakeholders, including citizens, governments, and so on. In general, scholars discussed at length how societal concerns, at times not fully justified or based on lack of proper information, can impede the implementation or adoption of CN practices. This is particularly true in the case of the transportation sector. For instance, Shafique et al. (2022) noted that there are many societal concerns regarding the environmental benefits of electric vehicle technologies, which obstruct their wider acceptance, and Goulden et al. (2014) underscored the need to nudge people to make the right mobility choices such that transportation demand management is driven by a holistic view that explicitly brings together efficiency, equity, and sustainability. This implies a need to overcome social and informational barriers. Ku et al. (2021) reinforce the same point by observing that in order to seek the cooperation of multiple stakeholders to decarbonize the sector, governments need to formulate the right regulations and offer commensurate incentives to motivate action. Further highlighting the need to overcome informational and social barriers, J.-L. Lu and Wang (2018) noted the importance of using appropriate media to enhance passengers' knowledge of the emissions impact of aviation and the criticality of carbon offset programs. This is essential to not only develop a positive attitude toward carbon offsetting but also increase people's willingness to alter their travel behavior and offset their flights. In addition, Tattini et al. (2018) noted that strict travel times and the social behavior of low bus speeds could act as impediments to achieving CN targets in the transportation sector.

(ii) *Economic factors*: A well-established tenant in the pro-environmental behavior literature is that climate mitigation plans cannot be successful unless consumers agree to engage in the shared goals. In this regard, individual willingness to pay (WTP) has been found to be a key predictor of successful climate control policy implementation. However, scholars note that WTP, which entails a sacrifice on the part of users, is often low, and this inhibits the achievement of CN goals. Low WTP itself is driven by a series of factors, which have been examined by some of the reviewed studies. For example, Rotaris et al. (2020) examined air travelers' willingness to make financial donations for related projects and found that their WTP depended on the project description, its effectiveness in reducing emissions, and environmental awareness, along with their socio-demographic profile. This finding indicates both a lack of economic resources and the importance of information and awareness.

Similarly, in their study on electric mobility, Al-Buenain et al. (2021) revealed that despite understanding the efficacy of using carbon-neutral mobility solutions, people show an unwillingness to switch to electric vehicles. The suggestion that the government should provide incentives and subsidies for switching to eco-friendly, e-mobility solutions indicates that there exists an economic barrier. Su et al. (2021) also observed that there was a lack of public interest in buying electric vehicles due to varying awareness levels and concerns about performance costs. Furthermore, past studies have highlighted the role of subsidies in promoting the use of electric vehicles, arguing that a lack of financial incentives, particularly in less developed areas, was a key discussion factor in switching to electricity in surface transport (R. Zhang and Hanaoka, 2021).

4.4. Agriculture

4.4.1. Agriculture: facilitators

A review of shortlisted studies considered under the agriculture sector shows that it has been the second largest contributor to climate change, with high emissions likely to continue into the future in most parts of the world. As drastic as this seems, the sector also offers a tremendous transformational potential with approaches such as Climate-Smart Agriculture. Academic researchers working on agriculture and CN have had some deep and rich discussions on how the sector can turn around and even support other sectors by providing alternative fuel sources. These discussions and conversations have helped us identify two key factors that can be considered as facilitators supporting the decarbonization of the sector: (i) agroforestry and livestock breeding management and (ii) organic fertilizer and soil organic sequestration. Both are discussed below.

(i) *Agroforestry and livestock breeding management*: Past studies have observed that, along with farming, deforestation has been one of the most significant reasons behind the emissions produced in the agricultural sector, and researchers have called for serious discussion on potential offsetting approaches (e.g., Rehman et al., 2021). Scholars have examined several approaches, such as reforestation (i.e., agroforestry) and livestock breeding management, to offset the GHG emissions from agricultural production and livestock. For instance, Anuga et al. (2020) contend that agroforestry and improved livestock breeding can significantly contribute to offsetting agricultural carbon emissions and achieving positive environmental outcomes. Similarly, Colley et al. (2020) suggest that a combination of two approaches—biosequestration in soils and aboveground biomass and using biomass as an alternative for fossil fuel—are effective in reducing on-farm emissions. In another reference to biomass, Murillo et al. (2021) revealed that the valorization of residual biomass through hydrothermal carbonization is effective in controlling air pollution caused by residential heating. Kingwell (2021b) also argued in favor of abatement of emissions in the sector through reforestation as a fundamental approach.

Some studies have particularly noted how sustainable land and livestock management can make the sector a part of the CN solution instead of being the second largest contributor to emissions. For example, Chiriacò and Valentini (2021) showed that small-scale, rural agricultural landscaping could serve as a viable solution for the mitigation or even complete offsetting of emissions from livestock, and Boaitey et al. (2019) evaluated livestock-based emission mitigation options based on the uptake of environmentally beneficial breeding practices for offsetting carbon. Acknowledging that crop production practices and ruminant livestock are substantial contributors to emissions, Torres et al. (2015) estimated emissions resulting jointly from cropland and livestock production to calculate the forest plantation area required to offset them. In their study, Doran-Browne et al. (2018) estimated the carbon balance of wool, prime lamb, and beef enterprises and demonstrated that offsetting emissions could be done effectively by using carbon sequestration in trees and soils.

(ii) *Organic fertilizer and soil organic sequestration*: Among the many suggested solutions to reduce emissions in the agriculture sector is soil carbon sequestration, which can help provide food to an increasing population while lowering GHG emissions (e.g., Albers et al., 2020; Doran-Browne et al., 2018). Discussing the adverse emissions impact of crop production, Uusitalo and Leino (2019) proposed the use of biochar produced from side flows and buffer zone biomass to counter the global warming caused by crop production. Other studies have also produced evidence supporting the usefulness of biochar as a way of lowering the sector's emissions. For example, Han et al. (2022) examined tea plantations to show that organic fertilizer substitution and the addition of biochar helped mitigate carbon development. Furthermore, Ghosh et al. (2020) suggested that following agronomic practices, including soil carbon sequestration, crop rotation and diversification, and residue management, to name a few, can significantly reduce emissions and help achieve CN targets. Along similar lines, Lind et al. (2016) suggested cultivating a perennial bioenergy crop on mineral soil as an effective low-carbon solution.

4.4.2. Agriculture: inhibitors

As in the case of other sectors discussed in the present study, the agriculture sector has not been able to achieve the desired level of CN so far, nor does it seem to be on the path to meeting the 2030 mandates. The studies included in this review have discussed several issues that have either reduced the efficacy of CN efforts made or completely obstructed the related initiatives from being introduced. By synthesizing these discussions, we have identified different inhibitors of agricultural CN, which can be summarized under two headings: (i) intensive farming and cultivation activities and (ii) livestock production.

(i) *Intensive farming and cultivation activities*: With the rise in population, the demand for food and, consequently, its cultivation have increased, which has been fulfilled through intensive farming of existing cropland or by increasing the amount of land being farmed. Past studies have noted that many activities/inputs related to crop cultivation, such as the use of synthetic fertilizers, drained organic soils, irrigation electricity, and agricultural film and tillage, are key sources of emissions (e.g., W. Huang et al., 2022), as were practices such as the open burning of crops in the fields (Singh et al., 2016). Offering a different yet practical perspective on achieving carbon neutrality, Kingwell (2021a) argued that reducing emissions via reforestation had an economic cost, and the spatial allocation of farmland for carbon sequestration was difficult due to social and political pressures. At the same time, Roman-Cuesta et al. (2016) revealed a very practical inhibitor in the form of uncertain other land use estimates that jeopardize the effectiveness of emissions mitigation efforts in this sector.

Noting that some cultivations, such as oil palm plantations undertaken in tropical peatlands, resulted in the lowering of groundwater levels and the release of CO_2, Marwanto et al. (2019) expressed concern about the exploitation of the vulnerable subsoil of cultivated peatland. Other studies included in the review have contended that international demand and trade increase emissions by driving deforestation (e.g., Pendrill et al., 2019).

(ii) *Livestock production*: In their study on emissions due to livestock, Grossi et al. (2019) argued that population growth has increased demand for livestock products, which has, in turn, increased pressure on livestock production systems to produce more livestock, causing further emissions-related challenges from activities such as feed production, enteric fermentation, and so on. Other studies have made similar observations. For example, Torres et al. (2015) discerned that large amounts of livestock emissions are related to enteric fermentation.

4.5. Construction

4.5.1. Construction: facilitators

The construction sector is known for its significant contribution to emissions. Past studies included in the review have discussed several aspects, including factors that increase emissions as well as those that decrease them in this sector. By summarizing their findings, we identified two critical facilitators that can help reduce emissions in the sector and support the achievement of CN targets: (i) carbon-neutral design and technical expertise and (ii) operational planning and construction methods.

(i) *Carbon-neutral design and technical expertise*: Given its high energy consumption and resultant emissions, the building sector requires effective emissions reductions (Rabbat et al., 2022). As a result, scholars have focused on the potential solutions extensively. Past studies have suggested that architectural designs aimed at reducing emissions and specialized knowledge and expertise for designing green buildings are key facilitating factors for achieving CN in this sector (e.g., B. Hwang and Ng, 2013). Specifically, Noguchi (2011) underscored how design choices, including internal layout, materials, systems, due consideration of sun positions for daylighting and heating gains, and the renewable energy technologies used substantially impacted the success of low-to zero-energy affordable housing. Other studies have also discussed the important role of building design and expert knowledge in minimizing emissions. For example, Tsirigoti et al. (2021) examined city-wide renovation strategies that reduce energy demand and improve the city's aesthetics. B. Huang et al. (2022) argued that refurbishing and redeveloping existing buildings should be considered an important approach to energy efficiency and decarbonizing the built environment. Continuing the focus on existing structures, Kern et al. (2021) discussed how heritage sites offered opportunities for transitioning into sustainable urban centers with low emissions despite various legal challenges. In a study showing that design choices are also pertinent as far as infrastructure and emissions are concerned, Y. Liu et al. (2022) contented that a sustainable design approach for bridge infrastructure can help achieve CN targets. Scholars have also discussed the importance of harnessing solar energy to reduce emissions in buildings. For instance, Middelhauve et al. (2021) provided evidence to show that some districts could leverage PV energy alone to achieve CN if they covered all available rooftops and facades with panels. In another study on building-transportation interaction, S. Cao (2019) examined the usefulness of a hybrid photovoltaic and wind turbine-supported zero-emission office building in terms of its interaction with electric vehicles to produce evidence of the positive impact of a renewable energy system.

Quite logically, past studies have pointed out that design improvements to lower emissions for decarbonizing built structures are possible only when the professionals involved have the appropriate technical education, awareness, and training to plan and execute the required changes and improvements. For instance, J. Zuo et al. (2013) emphasized that relevant know-how and the use of appropriate materials were important for making commercial buildings carbon neutral. As a result, scholars have suggested that pedagogical changes for better training professionals can be helpful. For instance, Hemsath (2017) critically analyzed architectural curricula to suggest areas for improvement such that educational programs can instill more effective ways of thinking about environmental design and reducing emissions. In addition, scholars have underscored the need to raise awareness, formulate clear guidelines, and build capacity for transforming residential buildings into more energy-efficient structures (e.g., Attia et al., 2022). As a case in point, Jackson and Kaesehage (2020) suggested that imparting technical training to calculate actual carbon emissions can help implement carbon calculation tools in the construction sector.

(ii) *Operational planning and construction methods*: In addition to the emissions generated by the built environment, construction equipment and processes also generate emissions. Some of the studies included in the review have emphasized this aspect, suggesting that the construction sector can reduce emissions through proper planning at the initial, operational, and activity levels. For instance, Szamocki et al. (2019) contended that instead of piecemeal efforts, developing integrated plans can help reduce emissions significantly at the operational as well as activity levels of the complete construction life cycle. In another study underlining the importance of planning in construction activities, including the consumption of building materials, Chi et al. (2021) recommended that sustained long-term efforts through incisive plans, policy mandates, and the formulation of industry standards were required to make the sector carbon neutral.

Other studies have reinforced the importance of planning from different perspectives. B. Huang et al. (2022) emphasized the need for strategic planning to moderate the consumption behavior of residents to produce positive CN outcomes. Similarly, Heisel et al.(2022) suggested that the existing built environment should be managed like a valuable carbon stock for the timely achievement of CN targets. In addition, past studies have discussed the need for improvement in macro-level planning to lower emissions in buildings. For example, H. Li et al. (2021) argued that it was important to reduce regional disparities in per capita emissions and to give them due consideration in carbon peak planning, assigning regional targets to reduce emissions, formulating energy policies for buildings, and allocating low-carbon resources.

4.5.2. Construction: inhibitors

Past studies have discussed, directly as well as indirectly, certain factors that impede the construction sector in the pursuit of its CN targets. In the context of the present study, these factors can be classified as inhibitors that hinder the efforts to reduce emissions and achieve decarbonization. Based on our content analysis of the shortlisted literature, we have organized these inhibitors into two categories as discussed in detail below: (i) socio-cultural and information concerns and (ii) economic and organizational challenges.

(i) *Socio-cultural and information concerns*: Socio-cultural dimensions are the normative differences and inequalities in society, which can drive negative attitudes toward social responsibilities and act as critical inhibitors of efforts to achieve CN. At the same time, demographical changes such as family types and energy consumption behaviors have a bearing on CN, as discussed in the context of urban buildings (B. Huang et al., 2022).

Moving to the issue of information and awareness, Alam et al. (2021) observed that the approach to engaging different stakeholders' support for nearly zero-energy buildings is important since their attitudes, understanding, and perceptions regarding these structures can vary. The study suggested that to achieve CN, information should be made available for consumers as well as experts in the sector through guidebooks, case studies, training, etc. In their study of factors impeding the adoption of sustainable construction practices, Durdyev et al. (2018) found a lack of knowledge and information as key barriers. In the case of commercial buildings also, scholars have noted challenges in terms of a lack of working definitions and measurement standards CN (e.g., J. Zuo et al., 2013).

(ii) *Economic and organizational challenges*: It is a commonly accepted argument that investors always prefer short-term profitable businesses over opportunities with longer payback periods. It is also rationally arguable to seek cost-effectiveness in any activity, including CN. Seen in this context, scholars note the challenge of ensuring that the renovation of buildings to improve their energy performance will be cost-effective (C. Zhang et al., 2021). A similar challenge exists in the case of roofing solutions for achieving energy efficiency, with different solutions having different payback periods (Abuseif and Gou, 2018). Underscoring the criticality of economic and organizational issues, S. Zhang et al. (2021) observed that incremental costs, administrative aspects, issues of technical feasibility and specifications, uncertain development goals, and an inadequate policy support system impeded the transitioning of existing structures into zero energy buildings. Another organizational—and perhaps global—issue in the renovation of residential buildings to make them more energy efficient is the complexities associated with the recycling of construction and demolition waste (C. Zhang et al., 2021).

In their study of factors impeding the adoption of the sustainable construction practices mentioned above, Durdyev et al. (2018) also listed government and cost-related aspects as key constraining factors and called for well-defined legislation and economic incentives to promote and support these practices. Relatedly, Ruiz et al. (2020) noted that issues in the management of the large quantity of construction and demolition waste were also a challenge at the policy level because of the potential for extensive environmental consequences.

5. Discussion

The objectives of our study were articulated through four research questions. We conducted a comprehensive literature search and analysis to respond to **RQ1.** and **RQ2.**, which queried about the facilitators that stimulate, motivate, and support the adoption and implementation of practices that could expedite the achievement of CN targets and the inhibitors that impede or obstruct the adoption and implementation of such practices, respectively. Specifically, we executed a robust search protocol on two prominent digital databases: Scopus and WoS. Thereafter, we filtered the congruent literature to arrive at a relevant set of 149 studies. After shortlisting the literature and applying quality checks at different stages, we conducted a content analysis to delineate the facilitators and inhibitors.

To address **RQ3.**, inquiring about how the facilitating and inhibiting factors differ from sector to sector, we first set the conceptual boundary of our study by specifying our focus on five sectors—manufacturing, energy, transportation, agriculture, and construction (METAC)—based on the ongoing discussion about their high contribution to emissions. Next, we consolidated the results of our content analysis to compile a table of facilitators and inhibitors across the selected sectors (see Table 1).

As presented in Table 1 and Fig. 2, each sector has a distinct set of facilitators and inhibitors. However, there are certain factors that are common across more than one sector. For instance, alternative fuels act as facilitators for manufacturing, energy, and transportation sectors. This is not surprising since a large part of the debate on lowering emissions has been about the replacement of fossil fuel sources with renewable ones (e.g., Kuittinen et al., 2021; Potrč et al., 2021).

In comparison to the distinct and specific sets of facilitators with limited intersection across each of the five sectors, we observe that many inhibitors are common across sectors and quite generic in nature. For instance, social, informational, financial, and economic barriers and economic and organizational challenges manifested as inhibitors in all five sectors. The debate around financial constraints, the lack of awareness, inertia on the part of various stakeholders, informational gaps, and the lack of consistent standards and measures of CN is not new; it is rather well-entrenched in the literature (e.g., Acampora et al., 2023; Buck et al., 2023). As evident from Table 1, limitations of financial, technical, and policy support have also inhibited CN efforts in all sectors except the transportation sector.

Table 1
Comparison of facilitators and inhibitors across the METAC sectors.

	Sub-themes	M	E	T	A	C
Facilitator	Input material substitution	✔				
	Breakthrough technologies such as additive manufacturing	✔				
	Remanufacturing/recycling	✔				
	Integrated smart energy systems		✔			
	Renewable energy alternatives		✔			
	Alternative fuels	✔	✔	✔		
	Material efficiency			✔		
	Urban planning and mass transit development			✔		
	Agroforestry and livestock breeding management				✔	
	Organic fertilizer and soil organic sequestration				✔	
	Carbon-neutral design and technical expertise					✔
	Operational planning and construction methods					✔
Inhibitors	Limited green and eco-design model approaches	✔				✔
	Lack of access to renewable energy sources	✔		✔		
	Limitations of financial, technical, and policy support	✔	✔		✔	✔
	Social, informational, financial, and economic barriers	✔	✔	✔	✔	✔
	Intensive farming and cultivation activities				✔	
	Livestock production				✔	
	Economic and organizational challenges	✔	✔	✔	✔	✔

M = manufacturing, E = energy, T = transportation, A = agriculture, C = construction.

Finally, to respond to **RQ4.**, we critically evaluated the literature and attempted to diagnose the limitations of prior findings. Our extensive content analysis of the shortlisted studies to identify factors facilitating or impeding the transition of the firms in METAC sectors into carbon-neutral enterprises helped us understand critical discourses in the area. The acquired insight also helped us form a critical view of the available evidence, enabling us to identify gaps and suggest future research imperatives. For ease of understanding and to maintain concordance with the narrative presented in our SLR so far, we have continued to use the facilitator-inhibitor lens to categorize gaps and potential research questions, (see Table 2).

6. Conclusion

The process of achieving CN involves a complex network of activities encompassing operations, processing, infrastructure, and more, posing social, economic, and environmental challenges globally. The complexity of CN practices is further aggravated by the constant pressure of trade-offs, such as the sustainability dilemma of balancing between economic gains and energy efficiency goals (Dolge et al., 2021). Given the intricate and comprehensive nature of the efforts required to achieve CN, our study focused on identifying and systematically discussing the key factors that facilitate or impede emissions reduction in firms operating in the METAC sectors. The findings of this study hold valuable theoretical and practical implications, as discussed in detail below.

6.1. Theoretical implications

Our study contributes to the scholarly literature in the following three ways: First, it is the only study to date to focus on the comprehensive set of facilitators and inhibitors that can impact the timeliness and extent of firms' efforts to achieve their CN targets. Since reducing emissions has emerged as a prime concern globally, our efforts to identify and explain such a comprehensive set of factors have extensive theoretical relevance and practical takeaways. The identification of inhibitors underscores the fact that, despite CN being a key concern, there are several factors that may impede firms' efforts to work toward achieving CN targets. Overall, by generating a comprehensive set of stimulators and impediments, we provide direction to scholars to undertake practice-sensitized research.

Second, this is the first SLR in the area to present a broad view of the ongoing efforts and conversations, focusing on the five key sectors of METAC. Most prior reviews on the literature around CN and emissions reduction have been rather narrow, focusing on specific topics such as low-carbon agriculture operations (Anuga et al., 2020), the decarbonization of energy-intensive industries (Nurdiawati & Urban,2021), the analysis of co-benefits associated with energy demand reduction (Finn and Brockway, 2023), and so on. By presenting a broad view and extensive coverage, our SLR can serve to guide future researchers as a central point of reference.

Finally, our study not only comprehensively synthesized the congruent literature, it also critically assessed it to uncover the gaps in findings and suggest potential research paths to motivate future research in the area. The identified gaps and potential research questions are suggested separately for both facilitators and inhibitors. Such comprehensive consolidation of gaps and future research paths can contribute effectively toward the enrichment of the scholarly literature around CN, which is still evolving.

6.2. Practical implications

Our study offers three key implications from a practice perspective. First, the set of facilitators identified by our study provides clear, indisputable action points separately for each of the five critical sectors of METAC. By doing so, we render support to the struggle to achieve CN

Table 2
Gaps in the literature and potential research questions.

Themes	Gaps	Proposed research questions (PRQs)
Facilitators	**GAP1**. While there is a discussion on the need to renovate old buildings to make them energy efficient, the literature does not discuss alternative, long-term solutions such as constructing CN cities and attracting people to relocate there. **GAP2**. Although wind and solar energy are acknowledged to help balance costs and support penetration into electricity markets, the granular aspects, such as wind and PV land prices, thermal energy storage capacity, demand-side management, and grid parity, to name a few, are still not well-understood. **GAP3**. The financial implications of CN initiatives are known to be high, mandating policy support, subsidies, and incentives, yet the question of how public and private institutions can jointly attain a common ground for CN remains unresolved. **GAP4**. Although the use of biofuels and hydrogen-based fuels has been recommended to achieve CN, the literature has not been successful in addressing stakeholder concerns about the use of renewable fuels. Policies for the large-scale utilization of biofuels have not been effectively developed and fully implemented. **GAP5**. The stakeholders' roadmap for switching to alternative fuels in transport remains unclear. Furthermore, the extent of the reduction in the carbon footprint of an airline using all-biofuels or biofuel blends is not known.	**RQ1**: What are the challenges in building and successfully managing new CN cities? **RQ2**: How can CN cities attract and incentivize private investors? **RQ3**: How can we determine regional differences in energy demand? **RQ4**: How can we overcome renewable energy storage issues? **RQ5**: What are the key factors that prevent the banking industry from funding CN projects? **RQ6**: How can government intervention and state-owned bank regulation support CN credit facilities? **RQ7**: What kind of checks and balances can credit institutions introduce to measure the CN progress of borrowing firms from time to time and reduce credit risk? **RQ8**: What could be an effective mechanism for determining whether a region is suitable for large-scale production of biofuels without affecting global food production? **RQ9**: What are the managerial challenges in promoting biofuel use to reduce fossil fuel consumption? **RQ10**: What are the exigent policy initiatives that can promote the large-scale use of biofuels as a substitute for fossil fuel? **RQ11**: Since biofuels and hydrogen fuels are made from limited renewable natural resources, how can large-scale biofuel demand be best fulfilled? **RQ12**: What are the effective pathways through which different industries can effectively replace fossil fuels with biomass to achieve CN targets in a timely manner? **RQ13**: What challenges does the transport sector (aviation and non-aviation) face in using blue hydrogen? **RQ14**: What factors affect the determination of a unified mechanism for calculating greenhouse gas emissions?
Inhibitors	**GAP1**. Despite the existing research focus on the growth and conservation of native forests to promote carbon sinks, the current understanding of carbon sinks and sequestration in forest management is limited. **GAP2**. Despite many studies referring to social concerns as inhibiting factors hindering the pursuit of CN, the current literature offers a limited understanding of the personality traits and demographics of the actors involved.	**RQ1**: To what extent are industry and urban parks sequestering carbon, and how long does it take for carbon to be sequestered in different regions and climates? **RQ2**: How do forest owners determine the payment mechanism and payback period for carbon sequestration? **RQ3**: How can we identify suitable plants for future large-scale planting? **RQ4**: How useful are the current models for calculating actual carbon sequestration in natural environments? **RQ5**: How does a stable leadership coalition among countries and firms help promote CN at the aggregate level? **RQ6**: How can social media be used to impact the resistance to change for CN driven by cultural values, family type, size, and consumption behavior? **RQ7**: What motivates people to share redundant and false information and knowledge about CN on social media, and how can it be controlled?

targets, with most of the sectors lagging on their emission control commitments. It is commonly acknowledged that despite the energy efficiency and decarbonization measures introduced in the recent past, increased industrial activities in the energy-intensive sub-sectors, such as wood processing and non-metallic mineral production, have reduced the impact of positive climate change counteractions introduced at different levels (Dolge and Blumberga, 2021). As one example, scholars have expressed concern about the alarming increase in the emissions of cement and construction industries (e.g., Belbute and Pereira, 2020; Elhegazy et al., 2023). There are multiple other instances of increased emissions occurring despite resolutions on CN, raising the question of whether the initiatives introduced to mitigate emissions were operational and effective enough to meet the CN targets mandated in the Paris Agreement. Similar examples are available in the context of the other four sectors, too, suggesting that key industrial sectors, known as the most polluting ones, are not on track to achieve CN and need corrective action in a timely manner. The comprehensive set of facilitators curated through our SLR provides specific and actionable inputs for firms of different sizes operating in these critical sectors to prepare their strategic plans accordingly. For example, the manufacturing sector can work collectively toward empowering R&D on breakthrough technologies such as additive manufacturing since they are one of the key facilitators of CN.

Second, our study reveals that in addition to the expected financial issues arising from the cost of technology and changes required to achieve CN, social and informational factors act as inhibitors (Bolwig et al., 2020; Schreyer et al., 2020) that need to be dealt with across the METAC sectors to make the implementation of CN practices more acceptable and efficacious. By highlighting these factors, our study indicates that regulators and other stakeholders should understand the fundamental nature of the problem before contemplating technology-oriented solutions. Accordingly, we recommend that firms and regulators should expend considerable effort and resources for creating awareness and engaging the community in CN initiatives such that people do not obstruct the efforts. At the same time, there is a lot of resistance to change at the institutional level, with the instinct to adhere to the status quo. We recommend constant engagement, active dialogue, and policy incentives as well as penalties to address the unwillingness to change or make sacrifices for the greater good.

Finally, our study underscores the fact that one size fits all does not work in the case of CN. We found a distinct set of facilitators and inhibitors for each of the five METAC sectors, with very few commonalities, particularly in the case of facilitators. This suggests that blanket policies, regulations, and technologies should not be formulated/implemented as an umbrella solution for achieving CN at all levels.

Instead, specific and tailor-made approaches, sensitive to typical sectoral issues, are required to ensure the achievement of CN targets in a timely manner. Hence, we recommend policy formulation at the national, regional, and local levels to be sector-specific, with inputs from experts drawn from respective sectors to make the policies more contextually relevant and effective.

6.3. Limitations and future research

Our SLR offers several useful insights for researchers, managers, and regulators. However, as in the case of any review study, it has certain limitations that should be acknowledged. To begin with, we searched the identified keywords on only two digital databases, Scopus and WoS. Due to this, we could have missed some congruent studies indexed in other databases. However, the potential risk of missing relevant studies is quite low since these two databases are very comprehensive, covering about 95% of the total scientific production in all areas. The risk of missing relevant literature is further mitigated by the fact that we undertook a backward and forward chaining search. Nonetheless, future review studies can expand the coverage to include other databases as well for identifying studies. In addition, we used carbon neutrality or carbon neutrality as keywords for searching relevant studies. Although carbon neutrality or carbon neutrality are commonly used words in this context, it is possible that some authors could have used some less common terms to indicate neutrality in this sense. We could have missed such studies. As a natural progression, future reviews can expand the list of keywords to check if any relevant study offering novel theoretical and practical insight were missed. In our concern for not missing relevant and potentially useful insight, we considered a substantial list of publishers. It is also important to acknowledge that despite taking all due precautions for quality assessment and proper content analysis, exclusion of vital findings, or presentation of evidence could have impacted the study results. Over and above expanding our work, we also recommend that scholars review the extant literature on the impact of the COVID-19 pandemic on various aspects of individual life and society (Abbass et al., 2022; Abbass et al., 2023; Begum et al., 2022) that could have had a bearing on the efforts to adopt and implement CN practices.

CRediT authorship contribution statement

Shalini Talwar: Conceptualization, Formal analysis, Methodology, Validation, Writing – original draft, Writing – review & editing. **Amandeep Dhir:** Conceptualization, Formal analysis, Methodology, Validation, Investigation, Writing – original draft, Writing – review & editing. **Adeel Luqman:** Methodology, Validation, Data curation, Writing – original draft. **Jaya Gupta:** Methodology, Validation, Data curation, Writing – original draft, Writing – review & editing. **Ritika Gugnani:** Methodology, Validation, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors certify that they have NO affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

Data availability

Data will be made available on request.

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