



# Analyzing the impact of COVID-19 on environmental innovations in manufacturing firms<sup>☆</sup>

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## ABSTRACT

COVID-19 has had a significant impact on the manufacturing industry, and manufacturers have responded to the crisis in different ways. This study investigates Norwegian manufacturers' response to the crisis, particularly how it has influenced their adoption of environmental innovations. More specifically, the study investigates whether firms choose "general" or "green" strategic responses to the crisis and how this influences the overall adoption of environmental innovations. In addition, the study investigates how the degree of environmental innovation adoption occurring before COVID-19 affects how the crisis impacted firms. The study adopts a quantitative research approach using survey data from 526 manufacturing firms—a representative sample of manufacturers in Norway. The findings reveal that those manufacturers the most environmentally innovative before COVID-19 were more impacted by the crisis. Moreover, firms adopted both general and green responses to the crisis, and the overall conduction of environmental innovations decreased during the pandemic. The main contribution is the empirical findings related to the overall impact of COVID-19 on sustainability-oriented manufacturing. The implications are discussed for both theory and practice.

## 1. Introduction

Two major global crises are now in the spotlight for leaders and policy makers: climate change and the COVID-19 pandemic. The former may no longer be considered novel, and there is an increasing amount of research on how businesses can reduce their negative environmental footprints to reduce the inevitable and undesirable consequences of modern industrial activity [1]. Businesses use environmental innovations to address and reduce their environmental footprints, and research has shown how such deliberate and strategic innovation practices are beneficial to firms' overall economic performance [2]. 'Environmental innovation' is a broad term that includes, for instance, improved circular economy practices [3], initiatives motivated by corporate social responsibility [4], transition to renewable energy [5], and 'eco-innovation' and 'green innovation' practices such as improving efficiency and new products that contribute to cleaning, healing, and recovery [6–8]. The COVID-19 pandemic struck during early 2020 and has continued to be a global challenge through 2021. The effects of high infection rates—resulting in stringent restrictions and lockdowns—have led to immediate and enormous challenges for businesses worldwide

[9–11]. The economic effects of the pandemic have been observed across nations and industries, and many firms were forced to abruptly cut every cost not essential for firm survival [12,13]. The purpose of the present paper is to investigate how the COVID-19 pandemic has impacted firms' focus on environmental innovations.

Recent research has called for a focus on how COVID-19 impacts environmental innovations [14] as a way to enhance our understanding of how external disruptions, such as COVID-19, impact the implementation of sustainability strategies [15–17]. The literature has discussed how one environmental impact of the pandemic is reduced emissions from reduced economic activity [18] and how firms acted deliberately and strategically to cope with COVID-19 [11,19]. The pandemic may be considered an opportunity for igniting sustainability transitions, on the one hand [20], while on the other hand, it has been shown to hamper firms' corporate sustainability efforts [21]. Nevertheless, the current literature relating to how COVID-19 has impacted environmental innovations is still nascent and scarce (cf [17]). Although COVID-19 represents a unique crisis in history [22], there is literature considering prior financial crises [23–28], health crises [29], natural disasters [30–32], agricultural crises [33], and urban riots [34]. Hence,

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managing in times of crisis, such as during COVID-19, is indeed not “business as usual” [35], and the pandemic has had significant impacts on how firms respond to crises, as well as the consequences of those responses, both generally and environmentally.

The present paper responds to recent calls [14,17] by answering the research question: *How are efforts toward environmental innovations impacted by a sudden exogenous shock such as COVID-19?* The current paper provides a novel research contribution by considering if, how, and to what degree innovations for the environment are impacted by major crises. The paper is timely because it addresses a current and important issue for practice, policy, and research [11,14,17]. Being one of the first empirical papers addressing environmental innovations and major crises by analyzing a relatively large sample (N = 526) of firms, the current paper motivates an increased research focus on *how* and *why* businesses pursue those opportunities that involve innovations for the environment when facing a major crisis. For policy, the current paper suggests that efforts to facilitate sustainable development should be nurtured by acute crisis support for the most impacted firms and strategic innovation support for all other firms. Thus, this paper complements recent research stressing the importance of support measures to ensure survival and continued innovations in businesses more generally [11,36].

The next section presents the literature background of the research on how firms pursue innovation for the environment and how major crises have impacted firms’ innovation activities. Based on the literature, a set of six hypotheses is postulated. In section three, the quantitative research methods applied to test the hypotheses on a sample of 526 manufacturing firms in Norway are presented. Then, a presentation of the analysis results is given, as well as the discussions and conclusions.

## 2. Literature background and hypotheses development

### 2.1. Environmental innovations

The adoption of environmental innovations—including, for instance, eco-innovation and green innovation—is still an immature research area but has been receiving increased attention and emphasis among researchers, practitioners, and policymakers [6–8]. Environmental innovations are commonly defined as “*new or modified processes, techniques, systems and products to avoid or reduce environmental harms*” [37]; p. 11) or “*innovation that improves environmental performance*” [38]; p. 1075). The European Commission [39] defines environmental innovation as “*any form of innovation aiming at significant and demonstrable progress toward the goal of sustainable development, through reducing impacts on the environment or achieving a more efficient and responsible use of natural resources, including energy.*” Although many definitions exist, a commonality is that the main aim of environmental innovations is to reduce environmental harm while using resources more efficiently [40], thus maintaining “natural capital” in the world [41]. For the current study, we will adopt Hojnik and Ruzzier’s [40] definition.

Research has identified several important drivers for implementing environmental innovations: *external factors*, such as regulations, market pull, technology push, and cooperation, as well as *internal factors*, including cost savings, capabilities, managerial concerns, and competitive outcomes [7,40,42]. Because firms are experiencing increasing pressure to implement environmental innovations, their interest in how such types of innovations can create competitive advantages has increased. A literature review including 100 studies about the relationship between sustainability innovations and competitiveness reveals that most studies have found that sustainability innovations lead to positive outcomes, such as increased value creation (e.g., profitability, market shares, sales growth, new market opportunities), cost savings (e.g., increased productivity), and increased nonfinancial assets (e.g., reputation, image, quality, and customer satisfaction) [2].

### 2.2. Environmental innovation and crisis impact

The implementation of environmental innovation is a complex process requiring experience and skills beyond common industry experience [43]. Christmann [44] suggests that the “best practices” of environmental innovation are path dependent, where path dependency indicates that where and what a firm does is a function of previous investments and routines [45]. Hart [46] argues that sustainability implementation can be seen as a kind of sequential logic of activities in which capabilities and resources are accumulated along the way. As Aragón-Correa and Sharma [47] state, “*The capabilities are complex and path dependent on the accumulation of, and the interaction between, resources such as physical assets, technologies, and people*” (p. 73). Therefore, we argue that firms that have already implemented environmental innovations to a high degree have accumulated enough resources and capabilities to continue to go along this “path,” even after an external shock like COVID-19. Put differently, for these firms, sustainability has already been incorporated into their strategies and become part of their daily operations. Thus, it is reasonable to assume that despite an external shock, sustainability will continue to be a highly important part of their business. Hence, we argue that these firms are better able to maintain “stability,” which is an important dimension of resilience [48]. In addition, firms that have adapted environmental innovation possess dynamic capabilities [49], which are defined as a firm’s ability to build and reconfigure competences to rapidly address changing environments [45]; p. 516). The ability to rapidly adjust to external environments has been proven important in responding to a crisis [50], and this ability could further indicate flexibility, which is another important dimension of resilience [48]. Thus, we postulate that firms with high environmental innovation adaptation are more flexible, have a higher degree of dynamic capabilities, and are more capable of maintaining stability, which can make firms more resilient to an external shock like COVID-19.

Further, Ding et al. [51] find that the stock prices of companies with a high degree of implemented sustainability measures fell less because of COVID-19 compared with other firms because of higher levels of trust among the stakeholders, who made a greater effort to support more sustainability-oriented firms after the shock. Similarly, Huang et al. [48] find that firms with higher sustainability engagement prior to COVID-19 have been less impacted by the pandemic because of stakeholder relationships, reputation, and innovation capacity. The capacity to innovate may be a result of a firm’s creativity [6,52], and creativity and experimentation are considered important factors in coping with COVID-19 [11,53]. Hence, firms with higher sustainability engagement are expected to be more resilient to negative impacts from the pandemic [48]. In this way, environmental innovation can contribute to reducing business risk [54,55]. Based on the arguments above, we propose the following hypothesis:

**H1.** Firms that conducted a high degree of environmental innovation before the COVID-19 outbreak have been less impacted by COVID-19.

### 2.3. Crisis impact and strategic response

COVID-19 has led to reduced supply for businesses because of lockdowns, as well as reduced demand for products and services because of reduced consumption and investments [56]; p. 1). The impacts from a major crisis such as COVID-19 force firms to respond strategically to adapt to novel market conditions and increase the likelihood of firm survival [57,58]. Previous research has pointed to two types of general strategic responses to crises. The first is strategic responses that are protective and reactive in nature, and these responses typically imply postponing investments and laying off employees [13]. The second type is proactive [25] and typically implies accelerating strategic actions [59], such as adopting new technologies [60] and innovative business procedures [61]. The perceived potential to leverage opportunities that arise during a crisis may result in firms’ proactive attitude toward the

situation, hence leading to proactively making strategic responses to the crisis. Examples include looking for new distribution activities, improving products or services, establishing new market channels or partners [56], business model innovation [50] and collaborating inter-organizationally [19]. Strategic responses to COVID-19 may also potentially take into account environmental sustainability because they can, either as a deliberate choice or because of a direct response to COVID-19, include measures that involve new environmental sustainability changes as part of the firm's new business activities. For example, this could include creative and experimental business practices [6,11]. Although COVID-19 has had a positive effect on the environment because of less energy use and emissions of harmful pollution because of lockdowns, travel restrictions, and quarantines [14,62], it has also positively influenced environmental awareness, sustainable consumption, and social responsibility [14]. Here, we distinguish the specific "green" strategic responses that directly take into consideration environmental sustainability from the more general strategic responses, hence proposing the following two hypotheses:

**H2a.** The impact of COVID-19 has led firms to make "general" strategic responses to the crisis.

**H2b.** The impact of COVID-19 has led firms to make "green" strategic responses to the crisis.

#### 2.4. Changes in environmental innovation

Research on how COVID-19 affects the implementation of environmental innovation is still lacking. Regarding socio-technical transitions, some researchers have discussed how external shocks, such as COVID-19, can change established policies and systems, leading to transitions toward increased sustainability and facilitating more sustainability-oriented businesses and consumption [63,64]. The pandemic has already altered economic activities, consumption, and energy demand worldwide [64,65]. Because of this, the industrial and public sectors may be more aware of, incentivized, and motivated to commit to solving sustainability issues [15,66–68]. Hence, researchers argue that the COVID-19 pandemic can be an opportunity to exploit and accelerate solving the sustainability challenge by a transition toward clean energy [64,65].

On the contrary, it can be argued that major economic challenges because of COVID-19 can lead to firms deprioritizing ongoing and planned efforts in environmental innovation activities in favor of survival strategies [15,65,69]. During crises like COVID-19, firms face increased liquidity issues and budget constraints, often resulting in reduced R&D and willingness to innovate and, thus, reduced innovation activities [70]. COVID-19 has had a negative impact on firm performance [71], leading to less room for environmental innovation adaptation. Thus, investments in environmental innovation become riskier and more uncertain regarding firms' performance outcomes [72]. In addition, policymakers have focused on stabilizing industries instead of continuing to push forward a sustainability transition [64], such as, for instance, how emission regulations in the US were eased for industrial firms to have better chances of survival. Easing regulations is likely to reduce the environmental innovation activities in firms because regulations are one of the most important drivers of environmental innovations [40]. Thus, based on firms' economic challenges, as well as changes in policies, we propose the following hypothesis:

**H3.** COVID-19 has negatively impacted firms' environmental innovation change.

Moreover, potential green and general strategic responses conducted by firms because of COVID-19, as hypothesized in hypotheses H2a and H2b, may materialize in environmental innovation activities. Hence, the following two final hypotheses are proposed:

**H4a.** General strategic responses have positively impacted firms'

environmental innovation changes during COVID-19.

**H4a.** Green strategic responses have positively impacted firms' environmental innovation changes during COVID-19.

The six proposed hypotheses can be combined into a conceptual model, as shown in Fig. 1.

### 3. Method

#### 3.1. Sample and data collection

A quantitative research approach was used. This research approach is appropriate because statistical methods can be used to generalize and uncover patterns and regularities from observable environments [73]. Quantitative research often follows an approach in which hypotheses are developed based on theory, followed by hypothesis testing [74]. Because the current study aims to investigate the relationships among the impact of COVID-19, environmental innovation, and strategic responses, a quantitative research approach was deemed appropriate.

The data were collected using a questionnaire. Manufacturing firms contribute highly to climate change and resource consumption [8] and have been severely impacted by COVID-19 [75]. Thus, the sampling criteria included all Norwegian firms within the NACE<sup>1</sup> code C–Manufacturing. For the sampling procedure, an initial list of firms was extracted from the Norwegian registry of commercial entities and consisted of approximately 8500 firms. Based on the available email addresses for the managers and/or business owners of commercial entities, the questionnaire was sent out by email in December 2020. The survey closed in January 2021. As expected, the authors received a significant number of email replies from potential respondents who responded that their firms were inactive or merely a hobbyist activity (e.g., manufacturing jewelry as a hobby). In addition, the authors received a significant number of email error messages, indicating that the contact information was not valid. Based on extrapolation of the number of firms found as ineligible, the authors estimated that the list of 8500 commercial entities would contain between 3000 and 4500 actual manufacturing firms. A total of  $N = 526$  firms ultimately responded to the questionnaire, corresponding to a response rate of 11.7–17.5%. The response rate is deemed sufficient when considering comparable questionnaire-based studies [19,76,77].

To test whether the sample was representative of the whole population, two-tailed t-tests were performed on the following variables: number of employees, foundation year, turnover, profit, and labor costs. No significant differences were found between the whole population of firms and the sample. In addition, a comparison between the types of sectors within manufacturing showed that the distribution was similar between the groups. Together, these results indicate that the sample is representative of the entire population of manufacturing firms in Norway.

#### 3.2. Questionnaire design

The questionnaire was developed based on constructs used in prior research. To validate the questionnaire items before they were sent out to the manufacturing firms, a group of industry practitioners and peer academics were consulted, and the authors adjusted the questionnaire based on their feedback. The questionnaire contained questions regarding how the firms have been affected by COVID-19, what kinds of changes the firms have conducted in response to COVID-19, and the firms' prior and current efforts toward environmental innovation. In

<sup>1</sup> NACE is short for "Nomenclature des Activités Économiques dans la Communauté Européenne," which is a statistical classification for economic activities in Europe and is used in the public database of registered firms in Norway.

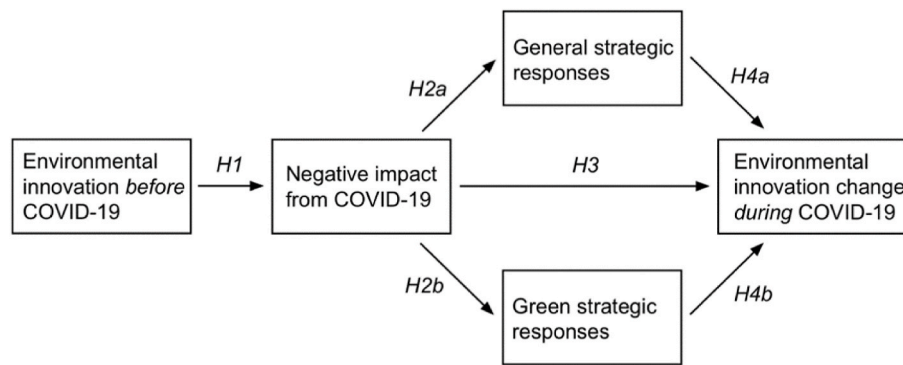


Fig. 1. Conceptual model.

addition, the questionnaire asked about the firm’s revenues right before the pandemic, firm size, firm foundation year, and type of firm (mainly goods producing, service delivering, or both). Descriptive statistics from the dataset are shown in Table 1.

We used the following constructs in the analysis: *the impact of COVID-19, green strategic response because of COVID-19, general strategic response because of COVID-19, environmental innovation before COVID-19, and environmental innovation change during COVID-19* (see the Appendix for the items). The respondents were asked to answer the questions using a 7-point Likert scale ranging from 1-Strongly disagree to 7-Strongly agree. The measures are presented below.

*The impact of COVID-19* consisted of four items developed based on Haneberg [19] and Riom and Valero [78]; in which the respondents were asked to answer how COVID-19 had affected their firm in terms of obtaining deliveries, demand, financing, and pressure on liquidity ( $\alpha = 0.797$ ).

*Green strategic response because of COVID-19* consisted of four items adapted from Burki et al. [79] and Przychodzen and Przychodzen [80] and were adjusted for the study. The measure included questions about firms’ different COVID-19-related green strategic responses—such as new green products, services, and customer groups—were concerned with the environment and redefined operation and production processes for sustainability ( $\alpha = 0.884$ ).

Table 1  
Descriptive statistics.

	Mean	S.D.	Min.	Max.
Firm age	31.28	34.020	0	363
Firm size	28.32	95.3968	0	1100
Firm revenue (2019)	79,258,536.41	381,021,695.0	0	7,000,000,000
Impact from COVID-19	3.34	1.33	1.00	7.00
Green strategic response	3.32	1.43	1.00	7.00
General strategic response	3.73	1.36	1.00	7.00
Environmental innovation before COVID-19	3.58	1.65	1.00	7.00
Environmental innovation after COVID-19	3.52	1.73	1.00	7.00
Environmental innovation change	-.05	.64	-2.78	4.00
Type of firm			<b>Percent</b>	
Service			9.5%	
Product			68%	
Both			22.5%	

*General strategic response because of COVID-19* consisted of four items developed from Cesaroni et al. [81] and included questions about what kind of changes the respondents have made, such as new sales channels, improved products or services, or new suppliers ( $\alpha = 0.831$ ).

*Environmental innovation before COVID-19* was adapted from the items of Chen et al. [82] and Doran and Ryan [83]. The measure consisted of nine items asking about the firm’s efforts before the pandemic in reducing the negative impacts on the environment, including reduced material energy use and emissions and increased recycling and reuse ( $\alpha = 0.946$ ).

*Environmental innovation change during COVID-19* was calculated by the difference between environmental innovation during COVID-19 and environmental innovation before COVID-19 (see the Appendix). *Environmental innovation during COVID-19* ( $\alpha = 0.958$ ) included the same items as in *environmental innovation before COVID-19*; however, instead, the respondents were asked about their environmental efforts during the pandemic.

*Control variables:* In the analysis, several control variables were used. More specifically, following other researchers (e.g. Refs. [84–87], we controlled for firm age, firm size, revenue, and type of firm. Firm age was measured by the year the company was founded, firm size was measured by the number of employees, revenue was measured by the revenue the firm had in autumn 2019, and type of firm was measured by the activity of the firm (mainly goods producing, service delivering, or both), where a dummy variable from 1 to 3 was used (1 = product, 2 = both, and 3 = service).

### 3.3. Data analysis

To analyze the data, the structural equation modeling (SEM) method was used. The analysis was conducted in Stata/MP version 16. SEM analysis is often used to test hypotheses using a theoretical model in which there are sets of causal relationships of latent variables measured by observable indicators [88]. Thus, one of its advantages is that it allows for estimation and hypothesis testing of unobserved constructs, which can have important implications for theory development [89]. SEM analysis consists of a measurement model and a structural model. To assess the measurement model, confirmatory factor analysis (CFA) was conducted to assess the relationship between the construct (or latent variable) and its corresponding variables, whereas in the structural model, the relationships between the constructs were assessed [88]. The measurement model must show acceptable levels of validity and reliability before one goes further with the assessment of the structural model [89]. CFA and SEM analysis were conducted using the maximum likelihood (ML) method.

Prior to SEM analysis, the data were checked for missing values and normality. Because Stata uses listwise deletion by default, in which observations with missing data are removed, it is important that the data are missing completely at random (MCAR) [73]. Little’s MCAR test was conducted, and the results showed that the MCAR assumptions were met

( $\chi^2 = 22.002$ ,  $df = 15$ ,  $p = 0.108$ ), indicating that the listwise deletion for missing values was acceptable [90]. Regarding normality, our analysis shows that the constructs have skewness and kurtosis values within the range  $[-1,1]$ , indicating that the constructs are within what is considered normal distribution [91].

#### 4. Results

##### 4.1. Descriptive statistics

Table 1 presents the descriptive statistics for the constructs and control variables. The table shows that the mean year of foundation was in 1990 (31 years ago), and the mean number of employees was 28. The mean revenue for the firms is approximately 79 MNOK (equivalent to ~\$9 million), and 68% of the firms are mainly goods producing, 9.5% are mainly service delivering, and 22.5% describe themselves as a combination of these two.

Table 2 shows the correlation table between the constructs and control variables.

##### 4.2. Measurement model

CFA was used to assess the measurement model. The table in the Appendix shows how all the variable loadings load above 0.6 to their respective constructs, indicating acceptable individual item reliability [92]. Further, the measurement model shows satisfactory validity and reliability because the average variance extracted (AVE) for all constructs exceeds 0.5, the composite reliability (CR) exceeds 0.6, and Cronbach’s alpha and Raykov’s reliability coefficients exceed 0.7 [73, 89,93] (see the table in the Appendix). Multicollinearity was tested using the variance inflation factor (VIF), in which all values were found to be below the acceptable levels of 3 [91]. The model fit indices show acceptable values, indicating an appropriate model fit [73,94]: RMSEA: 0.086, CFI: 0.913, TLI: 0.899, SRMR: 0.063.

##### 4.3. Structural model and hypothesis testing

The hypotheses were tested using the structural model, in which the model fit indices also show acceptable values, illustrating an appropriate model fit [73,94]: RMSEA: 0.069, CFI: 0.914, TLI: 0.899, SRMR: 0.087. Table 3 and Fig. 2 show the results of SEM analysis.

The results show that environmental innovation before the pandemic positively influenced the impact of COVID-19 ( $\beta = 0.17$ ,  $p < 0.01$ ). Hence, H1 is not accepted. In fact, the results illustrate that the opposite is the case—more environmentally innovative firms have been impacted more.

Further, the results show that the impact of the pandemic had a positive significant effect on the general strategic responses made ( $\beta = 0.50$ ,  $p < 0.01$ ) and on green strategic responses ( $\beta = 0.34$ ,  $p < 0.01$ ). Hence, H2a and H2b are accepted because the firms that have been

**Table 2**

Pairwise correlations.

	Age	Size	Rev.	Type	IC	GRSR	GENSR	EIB	EIC
Age	1								
Size	.295**	1							
Rev.	.240**	.659**	1						
Type	-.143**	-.053	-.090*	1					
IC	-.131**	-.026	-.035	.084	1				
GRSR	.073	.131**	.035	-.008	.348**	1			
GENSR	.038	.100*	.000	.028	.342**	.720**	1		
EIB	.199**	.131**	.133**	-.032	.208**	.376**	.304**	1	
EIC	.004	.052	.062	-.044	-.104*	.088*	.027	-.067	1

Age = Firm age; Size = Firm size; Rev. = Revenue (2019); Type = Type of firm; IC=Impact COVID-19; GRSR = Green strategic response; GENSR = General strategic response; EIB = Environmental innovation before COVID-19; EIC = Environmental innovation COVID-19; \*\* Correlation is significant at the 0.01 level (two-tailed); \* Correlation is significant at the 0.05 level (two-tailed).

**Table 3**  
Results of SEM analysis.

Model link	Standardized coefficients	Hypothesis support
<b>Direct effects</b>		
Env.inno.before → Impact covid	.17***	H1: Not supported
Env.inno.before → Green strategic response	.32***	
Env.inno.before → General strategic response	.26***	
Env.inno.before → Env.inno.change	-.011**	
Impact covid → General strategic response	.50***	H2a: Supported
Impact covid → Green strategic response	.34***	H2b: Supported
Impact covid → Env.inno.change	-.22***	H3: Supported
General strategic response → Env.inno.change	-.02 (NS)	H4a: Not supported
Green strategic response → Env.inno.change	.19***	H4b: Supported
<b>Indirect effects</b>		
Impact covid → General strategic response → Env.inno.change	-.008 (NS)	
Impact covid → Green strategic response → Env.inno.change	.063**	
Env.inno.before → Green strategic response → Env.inno.change	.060**	
Env.inno.before → General strategic response → Env.inno.change	-.005 (NS)	
Env.inno.before → Impact covid → Env.inno.change	-.037**	
<b>Control variables</b>		
Firm age → Env.inno.change	-.025 (NS)	
Firm size → Env.inno.change	.052 (NS)	
Revenue → Env.inno.change	.027 (NS)	
Type of firm → Env.inno.change	-.053 (NS)	

\*p < 0.1, \*\*p < 0.05, \*\*\*p < 0.01, NS = not significant.

impacted by COVID-19 have made strategic responses, both green and general, in their businesses.

Next, SEM analysis shows that the impact of COVID-19 had a direct negative influence on environmental innovation change ( $\beta = -0.22$ ,  $p < 0.01$ ). Hence, H3 is accepted.

Finally, the results show that general strategic responses had a nonsignificant direct effect on environmental innovation change, resulting in H4a not being supported. In contrast, the green strategic response shows a positive significant direct effect ( $\beta = 0.19$ ,  $p < 0.01$ ) on environmental innovation change, supporting H4b. Additionally, when looking at the indirect effects in Table 3, it becomes clear that the green strategic response has positively mediated the effect of the impact of COVID-19 on environmental innovation change ( $\beta = 0.063$ ,  $p < 0.05$ ). That is, those firms that implemented a green strategic response experienced positive changes in their environmental innovations. No such

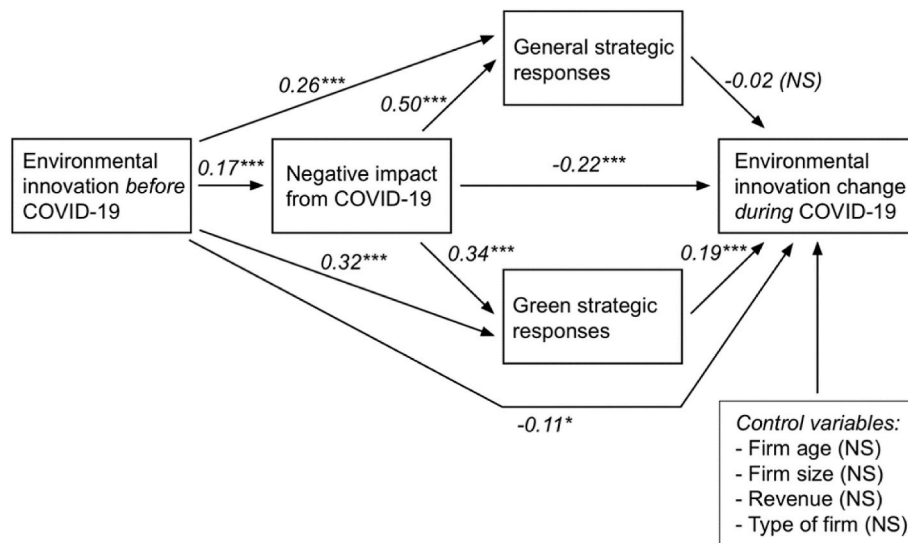


Fig. 2. Results of SEM analysis (only direct relationships are illustrated). \* $p < 0.1$ , \*\* $p < 0.05$ , \*\*\* $p < 0.001$ , NS=not significant.

mediating effect (NS) was observed from the impact of COVID-19 on environmental innovation change through a general strategic response.

Finally, Table 3 shows how the control variables of firm age, firm size, revenue, and type of firm do not have any significant effect on environmental innovation change in the model. Fig. 2 summarizes the results.

## 5. Discussion

The current study investigated the role of the COVID-19 crisis in the adoption of environmental innovations among Norwegian manufacturers. More specifically, it examined how the degree of environmental innovation before the pandemic influenced the impact of the crisis on firms (H1). We also assessed how the impact of COVID-19 has led Norwegian manufacturing firms to execute general (H2a) and green strategic responses (H2b). Finally, we investigated how the negative impact of the crisis (H3) and the general (H4a) and green (H4b) strategic responses have impacted the degree of adoption of environmental innovations during the pandemic.

Overall, the present study shows that the crisis has had a negative effect on the adoption of environmental innovations in the Norwegian manufacturing industry. However, there are several findings that contribute to a better understanding of why this is the case.

### 5.1. Environmental innovation before COVID-19 and the crisis impact

First, the analyses revealed that firms that had already adopted a sustainability strategy were more influenced by the crisis. This is an intriguing finding that is contrary to expectations from prior research and that deserves both discussion and further investigation. In previous research on environmental innovations, the adoption of such innovations has been conceptualized as a resilience strategy. For example, some studies discuss how more sustainable firms experience less financial and market risk [54,55], which can make them more resilient to external shocks because of support from key stakeholders and regulators, good market reputation, and innovation capacity [48,51]. In addition, highly environmentally innovative firms could be argued as being more flexible and possess high levels of dynamic capabilities. Based on these arguments, we expected that firms with a high degree of environmental innovation before the pandemic would be less impacted by COVID-19. The current study suggests that it is the other way around: firms with a lower degree of environmental innovation before the pandemic were less impacted than the “greener” firms. This indicates

that less “green” firms are better able to maintain business operations after an external shock like COVID-19 [95].

Perhaps the explanation lies in the specificity of the business risk factors. Previous research shows that environmental innovations often entail high investment costs, complexity, and uncertainty [96,97]. Environmental innovations also have long payback times [98]. For these reasons, environmental innovations can be more vulnerable to external shocks, such as the COVID-19 pandemic, in the short term. In other words, sustainability-oriented manufacturers might be positioning themselves toward a trajectory of a future market with stricter standards for environmental sustainability. Because an external market shock disrupts that trajectory, it can leave future-oriented firms with a greater problem than those focusing on an environmental *status quo*.

Another particularity of risk associated with environmentally oriented firms can be found in their supply chains. Researchers argue that the firms least impacted by COVID-19 are those that can rapidly adapt to the changing environment [56,99]. During crises, firms that focus on their main strategies and competencies are the most resilient [100]. Previous research has found that dynamic firms with a flexible, diverse supply chain and network with a good culture of collaboration are more resilient to external shocks because they can adopt and reconfigure rapidly [101]. Similarly, Obrenovic et al. [102] find that shorter and more diversified supply chains with a network structure and high levels of decentralized decision making improve firms’ resilience toward external shocks. In fact, research has shown that during the pandemic, renewable energy suppliers were highly impacted, and many renewable energy supply chains were disrupted [65]. This may indicate that firms highly engaged in environmental innovations were more prone to the impact of COVID-19 because they depended on less diversified and more volatile supply chains. We suggest that more research efforts should be directed at understanding how firms with particularly strong sustainability strategies are affected by external market shocks.

### 5.2. Crisis impact: Environmental innovation change and strategic responses

The main contribution of the current study is the empirical investigation of the overall effect of the COVID-19 crisis on the adoption of environmental innovations in manufacturing firms. Because of the crisis, halts in production processes, disruptions in supply, heterogeneous decreases in demand, and similar occurrences around the world, it is reasonable to assume that firms have paused or stopped their focus on environmental innovation activities and concentrated on daily

operations and firm survival. This assumption is also supported by the present study, which has found that COVID-19 had a direct, negative influence on the adoption of environmental innovations in the Norwegian manufacturing sector. This finding is consistent with Barreiro-Gen et al. [21]; who show that because of COVID-19, firms reduced their efforts in environmental issues, regardless of how long the firms have worked with sustainability. In addition, Zhang et al. [103] conclude that among Chinese firms, environmental sustainability was the least prioritized pillar during and after COVID-19; instead, they prioritized the social and economic pillars. Similarly, Hosseini [104] finds that the renewable energy transition has slowed down because manufacturing firms have been forced to put renewable energy technology projects on hold to focus on other activities. In their study of COVID-19's impact on firms, Zou et al. [105] show that COVID-19 impacted firms' innovation efforts because their R&D processes were hampered. In addition, nearly half of the surveyed firms expected financial losses because of the pandemic [105], which can explain why firms divested into environmental innovation. Moreover, COVID-19 had a negative effect on firm performance [71], and together with reduced liquidity, firms are meeting increased challenges in both ongoing and future sustainability projects [65]. Thus, the reduced adoption of environmental innovation may indicate a crisis response in which firms narrow their business scope by focusing on cost and complexity reductions to maintain liquidity and long-term recovery [50,106]. Hence, because of the financial and market risks associated with the COVID-19 pandemic, environmental innovations lose priority [69].

However, the current study shows little support for the notion that there is a general focus on the *status quo*, nor is there a lack of strategic response. In contrast, COVID-19 led to significant business responses among manufacturers (see Fig. 2), more so among those most affected. This shows how crises can lead to opportunities for strategic renewal and innovation [70,106]. The current study has shown that COVID-19 led to a broad range of general strategic responses, such as new sales channels, improved products or services, redefined operations, and production processes. In addition, it led to green strategic responses, including new green products or services, new green customer groups, and redefined operation and production processes for sustainability. These findings imply that COVID-19 has influenced firms to implement changes to adjust to their new external environment, but also to pursue the new business opportunities that come with these changes. In line with this, Riom and Valero [78] find that since the COVID-19 outbreak, many firms have adjusted their business operations, including adopting new technologies, management practices, and capabilities. During a crisis, firms can find new opportunities because of the changed environment, leading to new temporary or long-term business models [50]. These types of changes can be motivated by preparing for similar occurrences in the future and by becoming more resilient and flexible [101]. This shows that although the pandemic has led to challenges for firms, on the one hand, it also drives firms to look for new opportunities for innovation, on the other hand [56].

The changes observed among firms can be seen as dynamic economic resilience, in which firms increase the speed of recovery from an external shock [95]. In fact, research has found that manufacturing firms were the most negatively impacted compared with other industries [107], and the findings of the current study suggest that the strategic responses are a direct result of the negative impact from COVID-19 and that they have initiated a range of changes in the industry. However, it remains to be seen what the long-term consequences will be. Will the innovations implemented during COVID-19 put a lasting imprint on the manufacturing industry, or will companies revert to old ways when the dust has settled?

Finally, even though the results show that COVID-19 has an overall negative effect on the adoption of environmental innovations, it is interesting to note that the relationship is positively mediated by green strategic responses (see Table 3). This means that a significant number of firms chose to respond to the crisis by increasing their environmental

innovation efforts, despite the other negative effects imposed on them by the pandemic. Even though the effect from environmental responses was canceled out by the more numerous general strategic responses, the current study shows that firms can use external shocks as an opening to look for new green opportunities; especially, we observe that this is more common for those firms that have already implemented environmental innovations to a certain extent.

### 5.3. Limitations and further research

The current study has its strengths in representing a population of manufacturers. The limitations are predominantly from the time dimension and particularities of the country context. Because the current study was limited in time to activities and outcomes during an ongoing crisis, it could be that the long-term effects are different. Hence, because of the limited time frame, we encourage future research to study the effects of COVID-19 on environmental innovation in the long term.

Furthermore, even though the manufacturing sector is global in nature, our sample of Norwegian manufacturers entails some particularities to the Norwegian context that might not transfer well to other country settings. Norway has a long tradition of focusing on environmental regulations in industry, and regulators have set ambitious goals for a long time. Norway is also one of the countries that has been the least affected by the COVID-19 pandemic, both economically and otherwise. It is not unlikely that the findings would be different in a country setting where environmental regulations are less strict and less prioritized and where the impact of the pandemic has been more severe. Thus, further research could study the research questions in industries other than the manufacturing sector and in different country contexts.

Finally, the present study did not investigate the specifics of the firms that are the least impacted by COVID-19. Future research should dig deeper into what characterizes firms that are more resilient to COVID-19 and how business managers can learn from the pandemic for future scenarios.

## 6. Conclusion

The current paper studied the effect of COVID-19 on environmental innovation in manufacturing firms in Norway. Overall, the COVID-19 crisis had a negative influence on the adoption of environmental innovations in the industry. The crisis had a more negative impact on firms that were the most environmentally innovative, or "greener," before the pandemic. Finally, COVID-19 has imposed both general and green strategic responses in the firms most severely hit by the crisis; these firms also responded most actively to a broad range of strategies. Hence, the notion that they simply pause environmental development processes or revert to old and safe practices is inaccurate. However, the tendency for general strategic responses that crowd out green responses leads to the overall finding that the pandemic has had a negative effect on the adoption of environmental innovation among manufacturers. Overall, these findings have important contributions to theory, policy, and practice.

Regarding the theoretical contributions, the study contributes to both the growing crisis management and COVID-19 literature, as well as the environmental innovation literature, by demonstrating how external market shocks work as a barrier and downgrade for environmental innovations. In short, the results show how external shocks slow down the green transition, not by a lack of innovation, but rather from an abundance of it, where environmental innovations are crowded out by other strategic responses. It also shows how proactive environmental strategies can be a liability in times of crisis if the crisis interrupts the projections of how strict and fast new environmental standards and regulations are implemented in the market. This is a new perspective in the literature that generally regards environmental sustainability strategies to be resilient. Finally, the study reveals that green strategic responses can positively mediate the relationship between the impact of

COVID-19 and adoption of environmental innovations. This shows that a significant portion of the firms in the sample increased their environmental focus as a strategic response during the crisis.

The reduced pace of adopting environmental innovations in such a large sector as the manufacturing one certainly also has policy implications. Governments have lost time on their projections to meet international obligations, and the current study demonstrates the importance of incentives stimulating environmental innovations during and after a crisis. Previous studies have shown the importance of political measures and support for firms to adopt environmental innovations in the future [65,104]. The current study shows the importance of stable market environments for firms to stay focused on improving their environmental performance instead of fighting for survival in a market crisis. Researchers have discussed how the downgrading of environmental sustainability among firms during COVID-19 may lead to an environmental rebound effect, where resource efficiency measures lead to increased resource use instead of a desired and expected decrease [103,108]. Thus, during external shocks that lead to market crises, businesses need increased support and incentives to

continue toward a green transition of society.

Finally, for practitioners, the most important implication is the issue of business risk and sustainability strategies as resilience strategies. Sustainability strategies might not be as resilient to market changes as previously argued, and an external market shock can significantly slow down the projections of demand for environmentally friendly products and services. Business managers should prepare for similar future external shocks by preparing management plans to decrease uncertainty and risk when it comes to environmental innovation implementation [72]. On the other hand, even though the results indicate that environmental innovations are less prioritized during COVID-19, we also observe some support for the strategy that crises can be mitigated by increasing attention to environmental innovations.

**Declaration of competing interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

**Appendix**

Constructs and items	Standardized factor loading	$\alpha$	RRC	AVE	CR
<b>Impact from COVID (IC)</b>		<b>.797</b>	<b>.803</b>	<b>.509</b>	<b>.801</b>
COVID-19 has affected our companies in the following ways:					
IC1 We have had or will have major challenges in obtaining deliveries	.61				
IC2 We experience or expect a large decline in demand for our products/services	.63				
IC3 We find it difficult to obtain financing	.70				
IC4 We experience or expect great pressure on our liquidity	.88				
<b>Green strategic response resulting from COVID-19 (GRSR)</b>		<b>.884</b>	<b>.811</b>	<b>.619</b>	<b>.864</b>
COVID-19 has affected the firm in making the following changes or adjustments:					
GRSR1 We have developed new green products and or services during the COVID-19 period	.67				
GRSR2 We have oriented ourselves toward new customer groups that are concerned about the green shift	.69				
GRSR3 We have redefined our operations and production processes to implement sustainability more efficiently	.88				
GRSR4 We have redefined our operations and production processes to meet new environmental criteria	.88				
<b>General strategic response resulting from COVID-19 (GSR)</b>		<b>.831</b>	<b>.832</b>	<b>.573</b>	<b>.840</b>
GSR1 We have used new sales channels	.65				
GSR2 We have improved products	.85				
GSR3 We have improved services	.86				
GSR4 We have used other suppliers and/or used alternative input factors that are available	.64				
<b>Environmental innovation before COVID-19 (EIB)</b>		<b>.946</b>	<b>.932</b>	<b>.657</b>	<b>.943</b>
To what degree did you before COVID-19 have measures to:					
EIB1 Reduce material use per unit of output	.72				
EIB2 Reduce energy use per unit of output	.80				
EIB3 Increase the use of renewable energy	.83				
EIB4 Reduce emissions of greenhouse gases	.91				
EIB5 We strive to reduce or eliminate impacts on local ecosystems	.91				
EIB6 Replace materials with less polluting or hazardous substitutes	.81				
EIB7 Reduce soil, water, noise, or air pollution	.90				
EIB8 Recycle waste, water, or materials	.68				
EIB9 Improve recycling and/or reuse of product and packaging after use	.69				
<b>Environmental innovation change (Environmental innovation after COVID-19 – Environmental innovation before COVID-19) (EIC)</b>			<b>Mean</b>	<b>SD</b>	
EIC1 Reduce material use per unit of output			-.14	1.257	
EIC2 Reduce energy use per unit of output			-.14	1.144	
EIC3 Increase the use of renewable energy			.12	1.059	
EIC4 Reduce emissions of greenhouse gases			-.03	1.037	
EIC5 We strive to reduce or eliminate impacts on local ecosystems			-.07	.996	
EIC6 Replace materials with less polluting or hazardous substitutes			-.04	1.107	
EIC7 Reduce soil, water, noise, or air pollution			.07	1.019	
EIC8 Recycle waste, water, or materials			-.19	1.159	
EIC9 Improve recycling and/or reuse of product and packaging after use			-.06	.994	

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