The Role of Collective Intelligence in Fostering Green Innovation: The Mediation Effect of Corporate Social Responsibility

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Abstract

Green innovation has become a primary driver for the development of entrepreneurial ecosystems. While collective intelligence, corporate social responsibility, and green innovation have been studied individually, integrated theoretical models remain limited. This study has two main objectives. First, it examines the direct effect of collective intelligence on green innovation. Second, it also examines the indirect effect of collective intelligence on green innovation by focusing on the mediating role of corporate social responsibility in this relationship. The research adopted a quantitative research design via a survey conducted among 745 Tunisian firms. The data collected were analysed using structural equation modelling (SEM) by means of AMOS version 23 software to test the relationships between the integrated variables in the research conceptual model. A re-tested scale was adopted in the study based on a literature review. The convergent and discriminant validity as well as Cronbach's alpha were tested and ensured that they met the requisite standard. A structural model was developed to confirm the abovementioned relationships. The quantitative results demonstrate that collective intelligence has a significant and positive effect on green innovation. Specifically, the study confirms that corporate social responsibility plays a partial mediating role in this relationship. Four key findings emerge: first, collective intelligence directly fosters innovative green practices; second, the interaction between collective intelligence and social responsibility strengthens firm outcomes; third, shared decision-making and knowledge exchange are vital capabilities; and fourth, the partial mediation highlights that social responsibility acts as a strategic bridge for sustainable initiatives. This study provides empirical evidence encouraging firms to invest in collective intelligence and capability development. The findings indicate that embedding corporate social responsibility into corporate strategy enhances the impact of green innovation. Ultimately, this integration supports genuinely sustainable decision-making processes within the Tunisian business context. Therefore, both theoretical and practical implications were suggested.

Key words

collective intelligence, corporate social responsibility, green innovation, Tunisian firms, corporate strategy, strategic decision making.

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Introduction

In today's context, shaped by climate change, industrial development, pollution, biodiversity loss, and growing consumer awareness of environmental issues, firms have been compelled to adopt environmentally responsible practices. Faced with these pressures, firms have turned to green innovation as a vital strategy, enabling them to ensure their long-term survival while sustaining a competitive advantage. Research by Wang et al. (2021) demonstrates that implementing green innovation fosters sustainable development and conserves resources by producing environmentally responsible goods and services. Moreover, studies (Fei et al., 2016; Karimi Takalo et al., 2021) indicate that green innovation is no longer confined to product design or manufacturing; it also extends to

sourcing and marketing, thereby broadening its contribution to environmental sustainability. Beyond this expansion, green innovation often requires profound organisational transformation, fostering exchange, knowledge sharing, and the pooling of collaborative efforts. Central to this process is collective intelligence, defined as the collaborative and creative interaction that allows groups to mobilise the knowledge (Weschsler, 1971), skills, and ideas essential for responsible action and innovation (Lévy, 1997; Malone & Bernstein, 2015).

The importance of collective intelligence is increasingly acknowledged. It enables organisations to better understand and analyse stakeholder expectations and to identify the most effective solutions to social and environmental challenges (Weschsler, 1971). In this way, collective intelligence serves as a key driver of corporate social responsibility.

Recognising the importance of a robust theoretical framework for addressing this research objective, this study draws on the Knowledge-Based View (KBV) proposed by Grant (1996). This perspective posits that knowledge is a strategic resource and a source of sustainable competitive advantage (Del Giudice & Maggioni, 2014). The works of Nonaka and Takeuchi (1995), Spender (1996), and Kogut and Zander (1992) underscore the critical role of exploring, developing, and sharing knowledge in implementing sustainable innovation practices within firms. Building on this perspective, Sassi et al. (2022) demonstrated that collective intelligence is a key strategic resource that allows firms to optimise knowledge transformation processes and mobilise collective efforts toward innovative and sustainable solutions. Moreover, the interaction between collective intelligence and corporate social responsibility (CSR) promotes knowledge creation and sharing, facilitating the emergence of green and socially responsible innovations (Nonaka & Takeuchi, 1995; Del Giudice & Maggioni, 2014). However, research examining the simultaneous relationships among these three variables remains limited (Shahzad et al., 2020; Feifei et al., 2022; Liao et al., 2022).

The present study seeks to answer the following research question: To what extent does collective intelligence influence green innovation through CSR in industrial firms? To address this question, we first present the theoretical framework of collective intelligence, green innovation, and social responsibility, emphasising the direct and indirect relationships among these concepts. We then outline the results of a survey conducted with 745 Tunisian industrial firms. Finally, we discuss the main findings and highlight the theoretical, practical, and managerial implications, as well as the study's limitations and directions for future research.

1. Literature review

1.1. The relationship between collective intelligence and green innovation

Environmental issues now play a central role in corporate strategies, reflecting a growing awareness of their importance. Protecting the environment, reducing pollution, and optimising resources have become priorities for organisations. They are thus seeking to enhance their performance and differentiate themselves in an increasingly competitive market (Cisneros Chavira et al., 2023). This evolution is not occurring in isolation; it is part of a context in which stakeholder expectations, whether regulatory, economic, or societal, are pushing firms to integrate more sustainable practices into their operations. Faced with these challenges, green innovation appears to be an essential driver for initiating the necessary transformations. It is a strategic response to new environmental requirements. Many researchers (Kneipp et al., 2019; Soewarno et al., 2019; Szutowski, 2021) emphasise its crucial role in the competitiveness and growth of firms. In fact, green innovation not only enables firms to respond to current and future environmental challenges but also creates new development opportunities. It also helps strengthen organisations' competitive positioning (Severo et al., 2017; Kneipp et al., 2019).

Extensive literature further underscores the multifaceted nature of green innovation. According to Kemp and Pontoglio (2007), green innovation encompasses products, production processes, services, management methods, and business models that, throughout their life cycle, mitigate environmental risks, pollution, and resource-related impacts, including energy consumption. This broad definition

is further developed by Eiadat et al. (2008), who describe green innovations as initiatives aimed at preventing pollution, reducing waste, and adopting environmental management practices. Other researchers stress its collaborative dimension. Karimi Takalo et al. (2021), for instance, argue that such innovation depends on firms' ability to mobilise external knowledge and collaborate with diverse stakeholders to develop solutions that are both sustainable and competitive. For their part, Chen et al. (2006) offer an even broader perspective, encompassing both tangible and intangible aspects, to minimise the environmental footprint of products and processes. Bekk et al. (2016) add that this approach is often driven by strict regulations or growing demand for environmentally friendly products.

These varied approaches demonstrate that green innovation is not limited to technological or strategic choices but also relies on collaborative dynamics and knowledge sharing.

Green innovation is largely influenced by collective intelligence, understood as a group's ability to collaborate, share knowledge, and generate innovative solutions. In this context, the work of Lee and Jin (2019) highlighted the decisive role of collective intelligence in enhancing innovation processes within firms. They showed that in environments where collective intelligence is highly developed, creativity, the pursuit of innovative solutions, and organisational dynamics are significantly strengthened. Similarly, Boder (2006) argues that collective intelligence drives knowledge development, which in turn fosters creativity and innovative solutions that enable firms to address the challenges they face. Thus, firms continually seek development paths that balance environmental responsibility and competitiveness. According to Engel et al. (2014) and Woolley et al. (2015), this goal can only be achieved through collective intelligence, which is considered an essential driver of green innovation advancement. Indeed, collective intelligence promotes joint decision-making and knowledge sharing, reducing individual biases and fostering innovative, sustainable ideas to address complex development challenges (Lee & Jin, 2019). In summary, collective intelligence drives green innovation by fostering knowledge sharing, creativity, and organisational dynamics that promote the implementation of new, environmentally friendly practices. Hence, the first hypothesis of this study is:

H1: Collective intelligence has a significant positive effect on green innovation.

1.2. The relationship between collective intelligence and corporate social responsibility

The concept of corporate social responsibility (CSR) has attracted growing attention in the literature in recent years (Freeman and McVea, 2001; Kolk, 2016; Vilanova et al., 2009; Carroll, 1991; Garriga & Melé, 2004; Lee & Shin, 2010; Maignan, 2001). CSR encompasses all efforts a firm undertakes to protect the environment and meet the expectations of its stakeholders, thereby enhancing its reputation and legitimacy (Asrar-ul-Haq et al., 2017; Lee, 2020; Guo et al., 2022; Yun et al., 2019).

CSR should not be seen merely as an organisational stance. It is a comprehensive strategy built on collaboration, knowledge sharing, and organisational learning. In this context, collective intelligence plays a central role, enabling the identification of social and environmental issues with greater precision and stimulating synergy and interaction among employees. Notably, studies by Lee and Jin (2019) and Zhang (2024) demonstrate that these dynamics promote responsible behaviour, making collective intelligence a crucial driver for the success and sustainability of CSR practices. Accordingly, we formulate the second hypothesis of this study:

H2: Collective intelligence has a significant positive effect on corporate social responsibility.

1.3. The relationship between corporate social responsibility and green innovation

Corporate social responsibility (CSR) is a key driver of green innovation, serving as a catalyst for the adoption of sustainable and environmentally friendly practices. As highlighted by Naveed et al. (2023), firms engaged in CSR initiatives incorporate environmental and social concerns into their overall strategy, which in turn encourages them to explore innovative solutions to address ecological challenges. CSR is not limited to regulatory compliance. Instead, it embodies a profound transformation of business models, aiming to reconcile economic performance, social well-being, and

environmental preservation (Aguilera-Caracuel & Ortiz-de-Mandojana, 2013). This holistic approach prompts firms to reassess their processes, adopt clean technologies, and develop eco-friendly products and services, while meeting the increasing expectations of stakeholders, including customers, investors, employees, and local communities.

One of the key mechanisms through which CSR influences green innovation is its capacity to create strategic alignment between economic objectives and environmental imperatives. For instance, firms committed to reducing their carbon footprint or preserving biodiversity are often driven to invest in green technologies, optimize supply chains, and rethink production models (Aguilera-Caracuel & Ortiz-de-Mandojana, 2013). These initiatives, while motivated by ethical and regulatory considerations, also yield tangible competitive advantages. Firms that embed CSR into their strategy can strengthen brand image, build loyalty among environmentally conscious customers, and attract investors seeking sustainable opportunities (Karimi Takalo et al., 2021). As a result, CSR does not merely respond to external pressures; it becomes a strategic driver of green innovation and the creation of long-term value.

Moreover, CSR promotes responsible resource management, which is fundamental to the development of green innovation. By encouraging more efficient use of raw materials, reducing waste, and optimising production processes, CSR enables firms to minimise their environmental impact while enhancing economic performance (Feifei et al., 2022; Novitasari & Tarigan, 2022). For instance, a firm adopting CSR practices may implement recycling systems, reduce energy consumption, or design products with a lower environmental impact. Such initiatives extend beyond technical improvements; they entail a cultural transformation within the organisation, where employees and managers are encouraged to adopt more responsible and innovative behaviours that address environmental challenges and create value (Alauddin, 2023; Chen & Jin, 2023; Dzage et al., 2024). Furthermore, Wang et al. (2024) conducted a meta-analysis of 208,297 observations from 48 empirical studies and confirmed the significant effect of CSR on green innovation. Their findings indicate that this effect is particularly pronounced in SMEs and stronger in Western contexts than in Eastern ones. Building on this work, a meta-analysis by Gürler (2024) of 29 articles also confirmed a significant link between CSR and green innovation across sectors. This study further revealed an interesting regional comparison: the effect of CSR on green innovation is more significant in North America than in Europe. This divergence can be attributed to differences in organisational culture, institutional regulations, and market maturity between the two regions. Similarly, Hong et al. (2020) demonstrated that Chinese firms sharing their CSR practices benefit from new environmentally friendly innovations. Overall, CSR is a cornerstone of green innovation, creating a virtuous cycle in which responsible initiatives spark innovation that, in turn, strengthens corporate competitiveness and sustainability. Hence, the third hypothesis of this study:

H3: CSR has a significant positive effect on green innovation.

1.4. The mediating effect of corporate social responsibility between collective intelligence and green innovation

The preceding sections underscored the direct relationships among collective intelligence and green innovation, collective intelligence and social responsibility, and social responsibility and green innovation. However, current research rarely examines these three dimensions together, especially the mediating role of CSR in the relationship between collective intelligence and green innovation. Ji et al. (2019), however, emphasised the mediating role of government support in the relationship between green innovation and corporate social responsibility, drawing on panel data collected in China between 2008 and 2016.

Padilla-Lozano and Collazzo (2022) further examined the relationship between green innovation, social responsibility, and competitiveness. His findings suggest that CSR and innovation have a significant and positive impact on the competitiveness of industrial firms, particularly in developing economies.

Building on these studies, we previously analysed the link between corporate social responsibility and green innovation. We underscored that embedding green innovation within corporate strategies not only optimises production processes but also secures a lasting competitive advantage. Similarly, Bastien Scheid, CSR manager at the French group SCORUS, a firm specialising in transforming HR, finance, and information technology functions, provided additional insights in our study. The author emphasises the undeniable role of collective intelligence in generating innovative, environmentally sustainable value through the development of corporate social responsibility practices in French firms. In addition, study by Yun et al. (2019) demonstrate that firm value is increasingly associated with their commitment to CSR activities. Their findings reveal that collaboration, active employee engagement, and participation in the development of corporate strategies facilitate the identification of environmental and social issues (key determinants of CSR), thereby stimulating innovative solutions that align corporate objectives with broader environmental and social expectations. Accordingly, we formulate our fourth working hypothesis:

H4: CSR plays a mediating role in the relationship between collective intelligence and green innovation.

Figure 1 summarises all the hypotheses presented above.

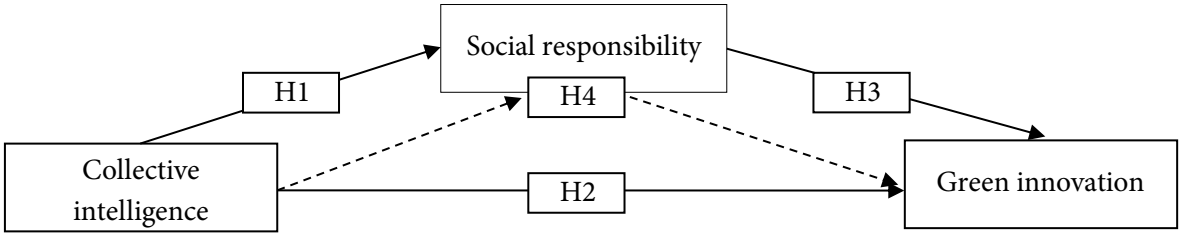

Figure 1. Conceptual model.
Source: Own elaboration.

2. Methodology

2.1. Sampling and data collection method

To examine the effect of collective intelligence on green innovation through CSR, a quantitative study was conducted using structural equation modelling (SEM) with AMOS 23. The study involved 745 industrial firms in Tunisia, which was selected as the research context due to its ongoing efforts to promote sustainable development practices that combine green innovation with CSR. Previous studies indicate that sharing green values and corporate engagement improve firm performance, particularly environmental performance (Amin, 2024; Aouay et al., 2023). Karra (2021) emphasised that the competitiveness of Tunisian firms depends on their willingness to adopt environmentally responsible strategies. The sample was determined using a non-probabilistic quota sampling method. This approach was designed to reflect the population's characteristics and ensure representation across all industrial sectors. According to the National Business Register (Répertoire National des Entreprises, RNE), Tunisia has 93,577 industrial firms. Table 1 presents the distribution of the population and study sample by sector.

Table 1. Distribution of Tunisian industrial firms by sector.

Sector of Activity	Percentage	Population	Sample Size
Textile and Clothing	19.7%	18,398	147
Agri-food	19.2%	17,934	143
Metallurgy and Metal Products	15.3%	14,344	114
Mechanical and Electrical Industries	18.4%	17,160	137
Chemical and Pharmaceutical Industries	11.4%	10,725	85
Construction Materials, Glass, and Ceramics	9.1%	8,580	68
Other Industries (wood, paper, plastics, etc.)	6.8%	6,336	51
Total	100%	93,577	745

Source: Own elaboration.

Data were collected using two methods. First, face-to-face interviews at the 12th Riyadh Trade Fair in Tunis (29–30 January 2025). Second, door-to-door surveys of firms in major cities, including Tunis, Nabeul, Bizerte, Sfax, and Sousse. Senior managers and executives were targeted. This ensured that responses reflected a thorough understanding of the concepts studied.

2.2. Measurement scales and questionnaire

This study aims to investigate the influence of collective intelligence on green innovation through CSR in industrial firms, using a quantitative questionnaire. The first part of the questionnaire includes general information about the respondents, such as the firm they work for, their position, and their length of service. The second part of the questionnaire includes measurement scales for the different variables in our study. All these scales have been tested and validated to ensure the relevance of the results.

To measure collective intelligence, we selected a 17-item scale divided into four dimensions: coordination, networking, diversity, and independence. This scale was developed by Kaur and Shah (2018) and tested and validated using structural equation modelling with 600 industrial firms in various fields. To measure corporate social responsibility, we chose the scale developed by Reverte et al. (2016), which adopts a holistic approach, the "Triple Bottom Line," that considers three dimensions: economic, social, and environmental (Asiaei et al., 2021). This scale comprises 27 items, classified into three dimensions. However, in this study, we have adopted the second-order model, as mentioned in the work of Asiaei et al., (2023), due to the strong correlation between the three dimensions: economic, social, and environmental. o measure green innovation, we adopted the scale developed by Li et al. (2024), inspired by the work of Chang and Chen (2013) and Chen et al. (2006). This scale comprises 10 items related to energy conservation, waste recycling, and pollution prevention.

3. Research results

To analyse the data collected from the questionnaire administered to a sample of 745 industrial firms, we employed a two-step analytical approach. The first step was exploratory, aimed at verifying the validity of the measurement scales. We applied principal component analysis (PCA) followed by an internal consistency assessment. Figure 2 presents the results of the first-order factor analysis.

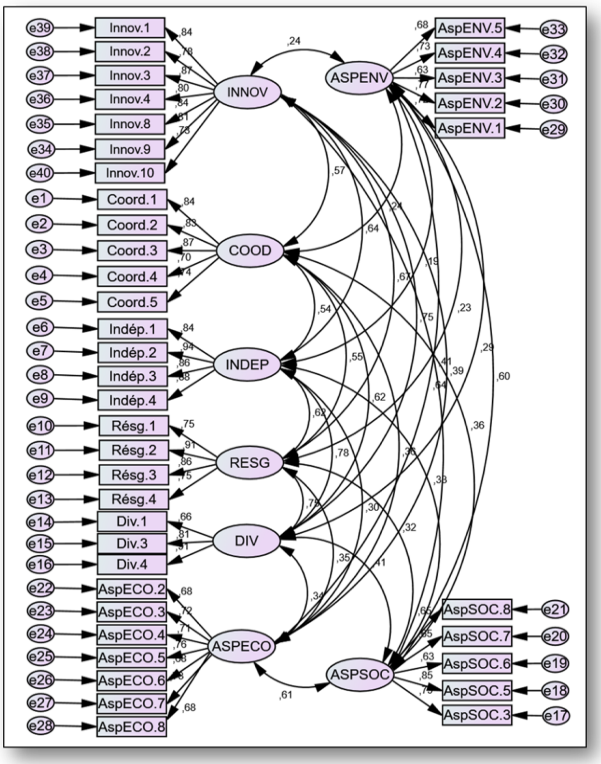

Figure 2. First-order model.
Source: Own elaboration.

The second step was confirmatory and conducted using structural equation modelling with AMOS 23 software. This stage enabled us to validate both the research model and the proposed hypotheses.

3.1. Results of the confirmatory factor analysis

Descriptive statistics of this study are presented in Table 2. The means of respondents' answers ranged from 3.62 to 4.18, with standard deviations of 0.913 to 1.64, indicating that responses are relatively dispersed and less concentrated around the average. Table 2 shows that the χ^2/df ratio is 4,8105, which is below the threshold value of 5. The RMR and RMSEA values are both below 0.1 and close to zero. In addition, the GFI, AGFI, NFI, and CFI are all close to 1. These results indicate that the model fit is satisfactory. Thus, we can conclude that the model adjustments are quite good. We also checked whether the data distribution is balanced and normal. Therefore, skewness and kurtosis values were examined. Skewness is considered acceptable when it is below 3, and kurtosis is acceptable when it is below 8. Based on the values shown in Table 2, we can assume that the distributions of variables were adequately spread.

Table 2. Descriptive statistics.

Abbreviation	Minimum	Maximum	Mean	Std deviation	Skewness	Kurtosis
RSE						
AspECO.2	1.00	5.00	4.0209	0.93361	-0.997	1.037
AspECO.3	1.00	5.00	4.1382	0.92637	-1.473	2,561
AspECO.4	1.00	5.00	4.2047	0.97546	-1.206	1.023
AspECO.5	1.00	5.00	3.8344	0.99606	-1.245	1.604
AspECO.6	1.00	5.00	3.8435	1.10259	-0.971	0.395
AspECO.7	1.00	5.00	3.9426	1.00357	-0.926	0.624
AspECO.8	1.00	5.00	4.1173	0.97852	-1.134	0.909
AspENV.1	1.00	5.00	3.9544	1.20020	-1.257	0.684
AspENV.2	1.00	5.00	4.0574	1.08001	-1.436	1.626
AspENV.3	1.00	5.00	3.5593	1.23433	-0.652	-0.534
AspENV.4	1.00	5.00	3.7627	1.13732	-1.015	0.469
AspENV.5	1.00	5.00	3.8227	0.99993	-0.715	0.122
AspSOC.3	1.00	5.00	4.1213	0.99327	-1.575	2.536
AspSOC.5	1.00	5.00	3.9400	0.97705	-1.058	1.125
AspSOC.6	1.00	5.00	3.7445	1.15954	-0.836	0.013
AspSOC.7	1.00	5.00	3.6767	1.10412	-1.033	0.616
AspSOC.8	1.00	5.00	3.6845	1.08614	-0.887	0.320
Collective intelligence						
Coord.1	1.00	5.00	3.7705	1.15486	-1.114	0.513
Coord.2	1.00	5.00	3.7953	1.19007	-0.913	-0.099
Coord.3	1.00	5.00	3.7510	1.27408	-0.995	-0.116
Coord.4	1.00	5.00	3.6532	1.16394	-1.001	0.407
Coord.5	1.00	5.00	3.6128	1.27334	-0.976	-0.076
Div.1	1.00	5.00	3.6780	1.20240	-0.978	0.125
Div.3	1.00	5.00	3.6115	1.16645	-1.161	0.528
Div.4	1.00	5.00	3.7523	1.33781	-0.971	-0.245
Indep1	1.00	5.00	3.6180	1.25739	-0.736	-0.497
Indep2	1.00	5.00	3.5984	1.38357	-0.755	-0.676
Indep3	1.00	5.00	3.5880	1.37955	-0.600	-0.925
Indep 4	1.00	5.00	3.6545	1.26689	-1.049	-0.050
Res.1	1.00	5.00	3.4302	1.24955	-0.747	-0.349
Res.2	1.00	5.00	3.5424	1.27865	-0.807	-0.435
Res.3	1.00	5.00	3.5332	1.21291	-0.852	-0.245
Res. 4	1.00	5.00	3.5971	1.15988	-0.919	0.258
Green innovation						
Innov.1	1.00	5.00	3.6858	1.26887	-1.013	-0.021
Innov.2	1.00	5.00	3.8318	1.14560	-0.811	-0.280
Innov.3	1.00	5.0	3.6767	1.32155	-0.887	-0.326
Innov.4	1.00	5.00	3.8501	1.11233	-0.717	-0.433
Innov.8	1.00	5.00	3.8422	1.14936	-0.930	0.124
Innov.9	1.00	5.00	3.7836	1.20056	-0.871	-0.101
Innov.10	1.00	5.00	3.8462	1.06072	-0.756	-0.047

Note: Model fit: $\chi 2$ (704, N = 745) = 3386.607 $p < 0.001$, normed $\chi 2$ = 4.8105, RMSEA = 0.070 SRMR = 0.073, CFI = 0.957, TLI = 0.941, NFI = 0.933, IFI= 0.957, *** $p < 0.001$.

Source: Own elaboration.

3.2. Measurement of convergent and discriminant validity

To determine whether the scale items intended to measure the same construct are sufficiently related, we adopted convergent validity, assessed through the CR (which must exceed 0.7) and the AVE (which must exceed 0.5). The data presented in Table 3 indicate that convergent validity was satisfactory and met the required criteria. Furthermore, we assessed whether the square root of the AVE for each construct (items in bold in Table 3) is greater than its correlations with the other constructs. The values in Table 3 confirm discriminant validity for all variables. Furthermore, the dimensions of collective intelligence: coordination, diversity, independence, and networking, are strongly correlated. The construct is also grounded in a coherent and well-established theoretical framework (Kaur & Shah, 2018; Aubouin-Bonnaventure et al., 2025). Taken together, these elements justify treating collective intelligence as a second-order latent variable. This choice helps reflect the overall conceptual structure and the interdependence of its components. The same reasoning applies to social responsibility. Its social, environmental, and economic dimensions show strong correlations and are supported by established theoretical work (Asiaei et al., 2021; Asiaei et al., 2023). Social responsibility can therefore also be considered a second-order latent variable.

Table 3. Convergent and discriminant validity.

Factors/ items	St. Loading	CR	AVE	MSV	Ma R(H)	COOD	INDEP	RESG	DIV	ASP SOC	ASP ECO	ASP ENV	INNOV
1- Coordination (α=0.904)		0.898	0.640	0.391	0.908	0.800							
Coord.1	0.842												
Coord.2	0.834												
Coord.3	0.865												
Coord.4	0.701												
Coord.5	0.744												
2-Independence (α=0.932)		0.933	0.776	0.613	0.941	0.536***	0.881						
Indep.1	0.843												
Indep.2	0.936												
Indep.3	0.858												
Indep.4	0.885												
3-Networking (α=0.889)		0.891	0.674	0.557	0.911	0.551***	0.616	0.821					
Resg.1	0.754												
Resg.2	0.909												
Resg.3	0.860												
Resg.4	0.750												
4-Diversity (α=0.839)		0.838	0.637	0.613	0.879	0.625***	0.783	0.747	0.798				
Div.1	0.656												
Div.3	0.813												
Div.4	0.906												
5-Social aspect (α=0.855)		0.840	0.516	0.375	0.863	0.360***	0.329	0.323	0.406	0.719			
AspSOC.3	0.788												
AspSOC.5	0.847												
AspSOC.6	0.632												
AspSOC.7	0.655												
AspSOC.8	0.646												
6-Economic aspect (α=0.883)		0.877	0.504	0.408	0.878	0.361***	0.297	0.354	0.340	0.612	0.710		
AspECO.2	0.678												
AspECO.3	0.716												
AspECO.4	0.711												
AspECO.5	0.764												
AspECO.6	0.685												
AspECO.7	0.727												
AspECO.8	0.684												
Environmental aspect(α=0.853)		0.834	0.503	0.408	0.840	0.239***	0.194	0.230	0.289	0.605	0.639	0.709	
AspENV.1	0.718												
AspENV.2	0.775												
AspENV.3	0.634												
AspENV.4	0.733												
AspENV.5	0.677												
Innovation (α=0.853)		0.930	0.657	0.559	0.934	0.566***	0.636	0.672	0.748	0.407	0.394***	0.244	0.810
Innov.1	0.838												

Factors/ items	St. Loading	CR	AVE	MSV	Ma R(H)	COOD	INDEP	RESG	DIV	ASP SOC	ASP ECO	ASP ENV	INNOV
Innov.10	0.728												
Innov.2	0.783												
Innov.3	0.871												
Innov.4	0.799												
Innov.8	0.837												
Innov.9	0.809												

Note: CR = Composite Reliability; AVE = Average Variance Extracted; MSV = Maximum Shared Value; ASV = Average Shared Value.
Source: Own elaboration.

3.3. Results of the structural equation modelling analysis

To investigate the effect of collective intelligence on green innovation (GI) through corporate social responsibility (CSR), structural equation modelling (SEM) was conducted using AMOS 23 software after confirming the reliability and validity of measurement instruments. Table 4 reports a Chi-square value with a χ^2/df ratio of 4.457, which falls below the recommended threshold of 5 (Roussel et al., 2002), indicating a satisfactory model fit, in line with Hair et al. (2014). Furthermore, the RMSEA and RMR values are 0.077 and 0.081, respectively, remaining below 0.1 and close to zero, thereby confirming an acceptable approximation.

Table 4. Hypotheses results.

Causality links	Links (CR)	Significance of relationships	Hypotheses Validation
H1: Collective intelligence → Green innovation	0.733 (14.177)	***	Confirmed
H2: Collective intelligence →CSR	0.458 (9.017)	***	Confirmed
H3: CSR → Green innovation	0.126(3.621)	***	Confirmed

Note: Model fit: $\chi2$ (757, N = 745) = 3373.949 $p < 0.001$, normed $\chi2$ = 4.457, RMSEA = 0.077; SRMR = 0.081, CFI = 0.962, TLI = 0.950, NFI = 0.936, IFI= 0.962, *** $p < 0.001$.
Source: Own elaboration.

The model fit is additionally supported by the incremental fit indices IFI = 0.962, NFI = 0.936, TLI = 0.950, and CFI = 0.962, all of which indicate a very good fit. All hypotheses were validated, with all relationships significant at $p < 0.001$ (Figure 3).

Figure 3. The Structural Model.
Source: Own elaboration.

Specifically, GI is significantly and positively influenced by collective intelligence (β = 0.733, p <0.001) and by CSR (β = 0.126, p < 0.001). Moreover, CSR is significantly and positively affected by collective intelligence (β = 0.458, p < 0.001). The R-square values demonstrate that a substantial proportion of the variance in GI is explained by collective intelligence and CSR, supporting the robustness and stability of the final structural model.

We applied Baron and Kenny (1986) method to examine the mediating role of CSR in the relationship between collective intelligence and GI (Table 5).

Table 5. Mediation results.

	Links (C.R.)	Significance of relationships
Step 1: Collective intelligence → Green innovation (c)	0.790 (15.198)	***
Step 2: Collective intelligence → CSR (a)	0.457(8.937)	***
Step 3: CSR → Green innovation (Considering the effect of the Collective Intelligence dimension on CSR) (b)	0.164(15.183)	***
Step 4: Indirect Effect of Collective Intelligence on Green Innovation: 0.075		
Full Mediation – Positive Indirect Effect avec Z = 4.458 et p = 0.000		

Source: Own elaboration.

This procedure involves four consecutive steps. First, to establish that there is an effect to be mediated, the direct link between collective intelligence and GI must be significant, which was confirmed (β = 0.733, p < 0.001). The coefficient is significant in the regression of GI on collective intelligence. Second, the effect of collective intelligence on the mediator, CSR, was tested and found to be significant. Third, the relationship between CSR and the dependent variable, GI, was examined while controlling collective intelligence; the effect of CSR on GI remained significant. This involves conducting a regression including both CSR and collective intelligence. Finally, to determine whether the mediation is partial or full, the direct effect of collective intelligence on GI was assessed in the presence of CSR. The link remained significant (β = 0.762, p < 0.001), confirming a partial mediation. Additionally, the respective t-values for the paths, ta and tb, are 8.973 and 15.183, and the Sobel test yielded Z = 4.458 with p < 0.001. Overall, the results presented in Table 4 indicate that CSR partially mediates the relationship between collective intelligence and green innovation.

4. Discussion

Based on these results, the SEM analysis revealed significant positive relationships among all model variables. Collective intelligence had a significant positive effect on green innovation (H1: β = 0.733, p < 0.001) and CSR (H2: β = 0.458, p < 0.001). These findings align with prior studies demonstrating that collective intelligence stimulates green innovation (Wang et al., 2021; Bekk et al., 2016; Boder, 2006; Engel et al., 2014; Mukhtar et al., 2025).

Collective decision-making, knowledge sharing, and employee collaboration support the accumulation of ecological knowledge and the generation of creative ideas. This, in turn, leads to environmentally responsible solutions. Executives confirmed that shared concern for environmental values encourages creativity, organisational dynamism, and the implementation of green innovation practices. Collective intelligence also positively influenced CSR by fostering idea exchange, coordinating efforts, and developing innovative solutions. This provides a conducive framework for integrating the economic, social, and environmental dimensions of CSR. These results are consistent with prior research showing that collective mobilisation and CSR practices mutually reinforce one another in promoting socially and environmentally responsible innovations (Boder, 2006; Kolk, 2016; Vilanova et al., 2009; Carroll, 1991; Maignan, 2001; Asrar-ul-Haq et al., 2017; Yun et al., 2019; Mukhtar et al., 2025)

Executives also noted that Tunisia's commitment to sustainable development and national initiatives promoting green entrepreneurship strongly influence corporate strategies. Collaboration, information sharing, and dissemination of sustainability knowledge encourage responsible practices across economic, social, and environmental dimensions. Collective intelligence and CSR thus form a complementary framework for developing and implementing green innovation. The third

hypothesis, linking CSR to green innovation, was also supported. CSR provides an environment conducive to strategies integrating environmental and social concerns. This enables firms to respond effectively to challenges. These strategies foster creativity, responsible resource management, and the development of environmentally friendly solutions (Wang et al., 2021; Karimi Takalo et al., 2021; Gürler, 2024; Hong et al., 2020).

Executives reported that CSR engagement transformed production processes, making them more efficient and environmentally sensitive while fostering the development of innovative, less polluting products.

Analysis of CSR's mediating role between collective intelligence and green innovation indicated partial mediation. Following Baron and Kenny (1986), the direct effect of collective intelligence on green innovation remained significant after introducing CSR ($\beta = 0.762$, $p = 0.000$). This suggests that CSR strengthens the relationship but does not fully explain the environmental innovation process. Firms rely on collaborative practices, knowledge circulation, collective competencies, and formal social and environmental engagement through CSR. These findings align with recent studies highlighting CSR's role in sustainable innovation. Chen and Jin (2023) show that CSR engagement fosters cleaner technologies through stakeholder involvement. Guinot et al., (2023) report that social responsibility toward employees supports organizational learning, a key mechanism for green innovation. Novitasari and Tarigan (2022) note that green innovation acts as a channel through which CSR improves organisational performance. Alauddin (2023) identifies green creativity as a central mechanism linking CSR practices to environmental innovation. The same author confirms the robustness of the positive relationship between CSR and green innovation across sectors and contexts.

Executives' feedback further supports these findings. CSR adoption led firms to revise production methods, favouring leaner and more environmentally responsible processes. Promoting sustainability values internally encourages collaboration, generates new ideas, and facilitates the development of less polluting products. CSR thus acts as a facilitator of green innovation, even if its effect is partial in the relationship between collective intelligence and environmental innovation capabilities.

Conclusions

This study aimed to examine the effect of collective intelligence on green innovation and to highlight the mediating role of CSR. The results of our study of 745 Tunisian industrial firms indicate that collective intelligence has a significant, positive effect on green innovation. In particular, knowledge sharing, skills mobilisation, leveraging experience, and coordination of efforts foster organisational creativity and opportunity identification, thereby driving the development of innovative and environmentally friendly products. These dynamics enable firms to address sustainability challenges and better meet current ecological and social demands. Furthermore, applying the Baron and Kenny (1986) method confirmed the partial mediating role of CSR in the relationship between collective intelligence and green innovation. In other words, collective intelligence alone is not sufficient to drive green innovation; its effectiveness depends on the implementation of CSR practices. CSR provides a supportive organisational framework that channels collective intelligence toward responsible and sustainable practices, thereby encouraging the development of environmentally friendly innovations.

Finally, although we successfully integrated three variables previously studied separately in the literature into a single theoretical model, the study has limitations, particularly regarding the exclusion of moderating variables considered crucial for robustness. Notably, these include CSR culture and management commitment. Indeed, CSR culture, embodied in the organisation's shared values and norms, plays a crucial role in transforming collective intelligence into concrete green innovation initiatives. Specifically, it aligns collective objectives with sustainability goals, reinforces organisational identity, and consequently stimulates green innovation initiatives (Melo & Garrido-Morgado, 2012).

Managerial commitment, in turn, drives the mobilisation of resources and the pursuit of proactive initiatives. The greater the managerial commitment, the more collaborative practices are encouraged and likely to result in innovative, environmentally friendly solutions (Rasheed et al., 2024; Liu et al., 2023). Given these limitations, it would be useful to consider moderating variables. A comparative study across other sectors could also shed light on how collective intelligence and social responsibility work together to drive green innovation.

From a theoretical perspective, we successfully integrated three variables previously examined separately in the literature into a single model: green innovation, corporate social responsibility (CSR), and collective intelligence. Our findings demonstrate that collective intelligence is a key driver of green innovation. Coordinating efforts, mobilising expertise, sharing knowledge, and enhancing the skills and collective identity of organisational members foster the recognition of opportunities and the development of innovative solutions. These dynamics allow firms to respond more effectively to environmental challenges, particularly those related to sustainability and ecological protection. Furthermore, our contribution highlights the pivotal role of CSR within this relationship. CSR serves as a strategic framework that guides and structures collaborative practices stemming from collective intelligence, thereby channelling organizational efforts toward the design of innovative projects that fully integrate social and environmental concerns.

From a practical and managerial perspective, we aim to provide managers with evidence encouraging greater investment in collective intelligence, notably through mechanisms that promote collective decision-making, knowledge sharing, and skills development. Our results also show that the benefits of collective intelligence are amplified when combined with CSR. Ultimately, managers should embed CSR into the firm's overall strategy and actively involve employees in order to achieve decisions that are not only innovative but also genuinely sustainable

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