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Analyzing the metaverse adoption for sustainable future: a moderated mediation model of green HR practices and environmental performance

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Smart usage of new technologies, like the metaverse, is altering the way organizations design and implement green HR practices. In this article, we explore how metaverse adoption, encompassing VR collaboration, immersive training, and digital HR spaces, affects firm environmental performance in the sustainability setting. Based on the Resource-Based View (RBV) and Ability-Motivation-Opportunity (AMO) theory, the model also treats green HR practices as a mediator and green transformational leadership as a moderator. The data were collected from HR managers working in the IT sector located in Riyadh, KSA, and the model was analyzed through SmartPLS 4.0. Findings indicate that metaverse adoption strongly influences the dimensions of green HR practices, which in turn positively influence firm environmental performance, therefore supporting the mediating role of green HR practices. Green transformational leadership positively moderated the relationship between green HR practices and firm environmental performance, suggesting that green transformational leadership will strengthen the positive relationship between GHRP and EP. This study adds to the sustainable HR and management literature by integrating the adoption of technology, green HR practices, and environmental performance and provides them in an integrated framework. The findings theoretically underscore the importance of the use of advanced digital applications to institutionalize sustainability HR projects and leadership styles that use directive and empowerment leadership practices combined. This model could be developed with cultural or organizational readiness antecedents to predict sustainability-related performance across the board.

KEYWORDS

firm environmental performance, green HR practices, green transformation leadership, metaverse adoption, sustainability

1 Introduction

The environmental degradation, reduction of carbon emissions, and resource inefficiency are the problems that have increased pressure on organizations worldwide. Under the three-pronged concept of sustainability, the environmental aspect has gained a greater level of prominence, a part of which is due to growing levels of climate-change rules and regulations, continued stakeholder activism, and international agreements on carbon neutrality. This has led to the surfacing of environmental performance as a measurable and externally reviewed measure of organizational sustainability. Hence, this forms a key outcome variable for both

theoretical and applied investigation. Compared to more holistic sustainability constructs, the environmental performance provides a better operationalization around particular measures, including emissions abatement, energy efficiency, waste management, and green innovation, and therefore provides a better empirical accuracy (Sarfo et al., 2024). The digital transformation and new technologies are the primary drivers of environmental improvement: new digital mechanisms allow tracking energy usage on a fine-granular level, optimizing resource management, enhancing supply chain visibility, and reducing operational wastage. However, the existing literature largely conceptualizes digital transformation as a technical project only and does not focus on the organizational and leadership processes that are compulsory to counterbalance digital investments with quantifiable environmental performance (Wang and Makhbul, 2024).

Despite the fact that the existing literature provides a connection between the outcomes of digital transformation and sustainability, there are three conspicuous gaps. To begin with, previous research often defines sustainability as a complex, multidimensional concept, which involves summing environmental, social, and economic performance into composite measures. This aggregation conceals individual lines of influence of digital technologies on particular aspects of sustainability. In this regard, environmental performance, specifically, requires operational changes, behavioral changes, and process re-configuration that can be quite different than the determinants of economic or social performance (Alshuaibi et al., 2024). Therefore, environmental performance should be isolated in theoretic specialty. Second, although leadership has been recognized as essential to sustainability transitions, the few existing literature challenges the role of green transformational leadership in shaping the association between digital transformation and environmental performance. Digital systems do not ensure the environmental benefits; the employees should internalize environmental values, green practices, and match the use of technology with the goals of the environment. Green transformational leadership, a synthesis of transformational leadership characteristics, namely visionary articulation, inspirational motivation, and intellectual stimulation, plus a clearly stated environmental orientation would be theoretically suitable to this end (Din et al., 2025; Mandip, 2012; Pham et al., 2019).

Leaders with such a construct could help to match digital efforts with pro-environmental values and, therefore, increase the effectiveness of digital transformation of the environment effect. Third, most of the available empirical information is based on the Western or manufacturing environment, and the technology-oriented emerging economies are underresearched. The information technology (IT) segment in Saudi Arabia (KSA) is a theoretically attractive landscape (Ding and Rafiq, 2025). Saudi Arabia is also making vigorous investments in digital infrastructure, artificial intelligence, and green economic diversification under Vision 2030. The IT industry takes a leading position on national digital transformation efforts, is technologically intense, and experiences increased sustainability requirements. It is possible to study this context to analyze how the digital transformation can be translated into the performance of the environment in the fast-paced, modernizing policy-driven ecosystem. Despite this, the interaction between digital transformation, leadership orientation, and environmental performance has been under-theorized and under-empirically tested, especially in emerging digital economies (Sang et al., 2024; Jia and Hou, 2024).

To fill these gaps, this study develops and empirically tests a model that defines digital transformation as the core impetus of

environmental performance and green transformational leadership as a mediating factor. This study contributes to the growing global need to take responsibility for the climate by focusing solely on the performance of the environment. This research, with the addition of green transformational leadership as a moderator, explains the behavioral and value-based processes that are needed to transform technological capability into ecological outcomes. This study places the analysis in the context of the IT industry in Saudi Arabia, and therefore, this study will provide contextually relevant evidence based on a strategically relevant emergent economy that is facing both a digital and environmental shift. By doing this, this study makes contributions to sustainability and leadership literature in elucidating: (1) why environmental performance should be given a special study; (2) how leadership can enhance digital sustainability performance; and (3) why the developing digital economies present a viable ground on which to experiment with such processes.

2 Literature review

2.1 Firm environmental performance

Environmental performance is a multidimensional aspect that reflects the level of how an organization reduces its ecological impact and, at the same time, enhances sustainability by intentionally and strategically planning its operations and adopting good operational behaviors. The notion consists of minimization of wastage, pollution, and elimination of resources, as well as encouraging long-lasting products and processes of production that are sustainable. Companies that show dedication to environmental performance normally introduce environmentally friendly industrial practices and develop protective mechanisms (Hazbi and Mounir, 2023), which are based on set environmental guidelines.

Environmental performance does not just relate to mere adherence to a formal set of regulations or an observance of the formal systems of environmental management. Instead, it requires a combination of ecological values that act as the culture of an organization and strategic decision-making. The proactive approach can help entities go beyond compliance and become environmental leaders as an important part of corporate strategy (Papademetriou et al., 2025). In this respect, environmental responsibility is not viewed as another cost burden, but as a long-term investment in reputation, innovation, operational efficiency, and competitive advantage.

Moreover, the environmental performance serves as a core component of corporate social responsibility. The environment in which a firm operates is not only the internal operations of the firm but also the sustainability of the supply chain and the wellbeing of the communities in which the firm operates. According to recent empirical studies, technological innovation is not the only factor that determines environmental performance and human capital. The formation of employees with green skills and environmental awareness also plays a role (Tanveer, 2025). When the goals of the environment are similar to the financial ones, the organizations are more prone to developing new solutions that could help to improve ecological performance and operational efficiency. Traditionally, business success was measured mainly on a financial platform, though these new perspectives are increasingly appreciating environmental performance as an important precursor of organizational success.

2.2 Metaverse adoption

The green economy has been emerging as a salient part of the broader agenda of sustainable development because of national and corporate interests. This transformation is supported by the fact that sustainability can increase competitiveness and enable the generation of long-term values. Digital technologies, such as the metaverse, are increasingly being regarded as facilitators of environmental and economic advantages through innovation, specialization, and better management of resources. The use of the metaverse is not only limited to operational efficiency but also has potential impacts on the environmental, social, and governance (ESG) performance. It has the potential to improve resource use and promote sustainable operations of multi-faceted supply chains because it can enable advanced data integration, virtual collaboration, and immersive digital environments (Zhang and Huang, 2024). At a larger scale, digital transformation helps improve the environmental performance through optimization of resource consumption, lessening energy consumption, and decreasing waste. In particular, artificial intelligence (AI) has the potential to enhance industrial procedures by minimizing the intensity of resources and environmental damage (Sklavos et al., 2024).

Sustainability can be further enhanced by the metaverse, which is an immersive and interactive virtual environment. It allows working remotely and virtual teamwork, with a possible decrease in business travel, reliance on infrastructure, and greenhouse gas emissions. It also sustains virtual training environments that sensitize the environment and instigate sustainable behaviors. Additionally, digital twins can enable companies to simulate real-time infrastructure and production systems and, thus, enhance monitoring, predictive analytics, and sustainable decision-making (Feroz et al., 2021). Such capabilities have the potential to improve the environmental performance by optimizing resources based on data and minimizing operational waste.

In the framework of Industry 4.0, digital networks of production systems can improve monitoring, better assess the impact on the environment, and more effectively distribute resources (Xu et al., 2025). These technologies are followed by the metaverse, which complements this transformation by allowing cleaner and energy-efficient business models. Immersive simulation, AI, and predictive analytics allow firms to simulate other production scenarios and evaluate the impact on the environment before its application, facilitating the promotion of green innovations and minimizing emissions (Xu et al., 2022).

The adoption of AI in the ESG strategies also enhances the sustainability prospects of the digital platforms. There is empirical evidence that AI applications can help to achieve better ESG performance through operational efficiency, improved governance mechanisms, and environmental innovation (Liu et al., 2025; Cui, 2025). Analytics powered by AIs facilitate climate response, social enabling, and enhancing corporate governance, and allow companies to streamline resources and minimize environmental impacts (Taleb and Kadhum, 2024). There is also strong evidence of AI adoption and green innovation strategies, which means that companies of any industry can be positive about the implementation of AI technologies into the sustainability program (Wang et al., 2024). On the whole, the implementation of the metaverse is a direction that is conditioned by AI and digital transformation technologies and is a strategic course that companies aiming to improve their environmental performance and further corporate sustainability should take.

2.3 Green HR practices

Green human resource practices (GHRP) conceptualization is a strategic framework that incorporates traditional human resource operations within the general environmentally sustainable goals (Jia and Hou, 2024). It is in this context that organizations strive to develop a workforce that does not merely appreciate the need to be environmentally responsible but also one that clearly espouses corporate environmental objectives. Green HR practices thus contain a continuum of environmentally conscious practices, namely recruitment, training, performance management, and reward systems, aimed at promoting sustainable behaviors in the workplace.

In addition to the normal administrative changes, the GHRP is set to instill the organizational culture and decision-making methods with environmental accountability. Once the sustainability principles are properly implemented in HR policies, the role transforms into a proactive driver of environmental responsibility that would spread its effects all across the enterprise. According to Sova et al. (2023), emerging technologies, including artificial-intelligence analytics, can also reinforce green HRM, with results in terms of identifying and strengthening environmentally friendly employee behaviors. Such technological tools can be used to prioritize the sustainability efforts and help reduce the amount of waste in the operations.

Green HR practices are also used to support objectives of environmental alignment of the organization with employee engagement. According to Zechiel et al. (2024), mutual green interrelation among companies and workers can contribute to a sustainable business model. However, when sustainability is incorporated into HR development activities, it can also provoke an ethical question regarding talent management and long-term planning of the workforce (Chang and Ke, 2023). Nevertheless, instilling environmental values in HR systems can strengthen organizational resilience and remain competitive in increasingly sustainable markets (Papademetriou et al., 2025).

The transition to green HRM requires the development of an organizational culture that would be more environmentally responsible in all the dimensions of the organization (Raghuwanshi and Acharya, 2020). When this type of integration is in place, the employees are motivated to take into consideration environmental considerations in their day-to-day operations and decision-making. Uthayasurian et al. (2019) contend that green HRM is a broader commitment of firms to the protection of the environment due to their structured policies and practices. Organizations should encourage employee participation in sustainable initiatives, which will improve the environmental performance and commitment of the workforce at the same time (Marrucci et al., 2023). Overall, green human resource practices offer a decisive channel of harmonizing the behavior of the employees with corporate sustainability plans. It is through such practices that organizations are able to attain a long-term environmental performance and also enhance their competitiveness in a marketplace that is increasingly becoming sustainability conscious.

2.4 Green transformation leadership

Green transformational leadership is critical in influencing the environmental awareness of employees and making them value collective environmental interests at the expense of personal gains. This act of leadership encourages people to take positive initiative in relation to environmental concerns and make their actions consistent with a common sustainability vision (Tran,

2023). Having a clear picture of the environment and supporting environmentally responsible behaviors will instill a feeling of responsibility in employees to protect natural resources (Chen and Wu, 2022). These leaders make their followers go beyond the official job descriptions and engage in environmental protection efforts (Zaid and Yaqub, 2024). Green transformational leadership facilitates the internalization of environmental goals by the employees since it entails the integration of sustainability in the organizational values instead of attempting to impose it as a command. Mansoor et al. (2021) argue that the long-term environmental initiatives are in need of the leadership that will spur innovation and encourage new ways to improve the environmental performance.

Pro-environmental behavior is also enhanced by green transformational leadership through the development of shared values and commitment. Employees are more likely to practice sustainability when they feel that the environmental strategies are significant and aligned with organizational purpose (Wang et al., 2024). This leadership style inspires collaboration, innovation, and engagement in green initiatives, which enhance the organizational buy-in to environmental goals (Gull et al., 2022). In comparison to transactional leadership, green transformational leadership is focused on the long-term environmental involvement and constant improvement (Casarrubias et al., 2025). Under these circumstances, workers have a higher chance of being engaged in green work, internalize green objectives, and actively take part in sustainability programs. Strong leadership engagement also enhances the engagement of top-management in performance monitoring of the environment and the introduction of green initiatives in the company (Huang et al., 2021).

Besides, green transformational leadership encourages self-leadership and climate-friendly behaviors among employees and thus improves organizational performance (Du and Yan, 2022). These leaders can strengthen accountability to positive environmental change by reinstating the value of stakeholders and encouraging the whole organization to embrace environmentally responsible behavior (Xiao et al., 2024). In general, green transformational leadership plays the role of one of the key determinants of environmental commitment, worker engagement, and sustainable organizational performance.

2.5 Theoretical background

The rationale behind the proposed model is four complementary theoretical lenses, which include the Resource-Based View (RBV), the Ability-Motivation-Opportunity (AMO) theory, Transformational Leadership theory, and the Sociotechnical Systems theory. Together, these frameworks explain how internal resources, employee competencies, leadership style, and technological integration can synergistically affect the green human resource (HR) practices, adoption of the metaverse, and environmental performance of the firm.

The resource-based view proposes that in the attainment of sustainable competitive advantage, resources that are valuable, rare, inimitable, and non-substitutable are utilized. The strategic assets are human capital and advanced technologies, which boost the performance of an organization including ecological results. Green competencies of the employees support green innovation, efficiency in operations, and high-level environmental performance. On the same note, other emerging digital technologies such as the metaverse are technological capabilities that can support sustainability efforts as long as they are properly incorporated into organizational systems.

The AMO theory also explains the effects of green HR practices on the behavior of employees. According to this model, the performance of the employees is determined by three factors that include ability, motivation, and opportunity (Elshaer et al., 2022; Zervas and Stiakakis, 2024). Green HR practices enhance the environmental competencies (ability), the pro-environmental attitudes (motivation), and the creation of favorable organizational conditions to take sustainable action (opportunity) of employees. The combination of these factors makes the employees more willing to engage in behaviors that improve environmental performance (Asfahani, 2023).

The Transformational Leadership theory can provide a clue on how leaders can influence the sustainability of the results. Transformational leaders express a significant environmental picture, encourage shared passion, and provoke creative thinking (Huang et al., 2021). Leaders play a role in the culture by leading through example and promoting intellectualism to promote environmental responsibility and technology adoption (Elshaer et al., 2025; Quttainah and Ayadi, 2024). This type of leadership will empower the execution of the green initiatives and increase their environmental performance effectiveness.

Sociotechnological systems theory focuses on the interconnectedness of social, e.g., organizational culture, leadership, and employee behavior, as well as the technological systems, green technologies, digital platforms, and metaverse spaces. When technology and human factors are harmonious and complementary, the performance of the environment will be enhanced. Inclusion of metaverse technologies in the supportive HR systems and visionary leadership structures improves sustainability outcomes through optimization of social and technical capabilities.

Put together, these theoretical lenses determine the interaction between metaverse adoption, green HR practices, and green transformational leadership as a factor in environmental performance. The interactions between these constructs cannot be explained by simple line associates, but rather through an integrated theoretical explanation because sustainability outcomes are a resultant product of the interactions of resources, human behavior, leadership, and technological systems.

2.6 Hypotheses development and justification

H1: The adoption of the metaverse has a positive effect on the green HR practices.

The implementation of high-level digital technologies such as the metaverse will improve organizational capabilities and transform the HR processes, considering the RBV and Socio-Technical Systems perspectives. Such platforms as a metaverse can promote virtual teamwork, immersive training, and digital activities that can reinforce environment-based recruitment, training, and performance frameworks. With the adoption of digital space in organizational operations, HR practices change with the aim of facilitating the sustainability goals (Al-Amin et al., 2021). Therefore, the adoption of the metaverse will have a positive effect on green HR practices.

H2: Green HR practices have a positive effect on the environmental performance of firms.

The AMO theory postulates that employees behave in a pro-environmental manner when they have the necessary capability, the drive,

and the chances. Green HR practices foster environmental competence, promote an attitude toward sustainable behavior, and offer institutional support for environmentally responsible behavior. Green HR practices improve the environmental performance of the firms by ensuring that workers work toward a sustainable organizational objective (Islam et al., 2022). Thus, the environmental performance and green HR practices are expected to be positively correlated.

H3: Green HR practices mediate the relationship between the adoption of the metaverse and firm environmental performance.

Although the adoption of the metaverse gives technological capacity, its environmental performance determines its effects on the environment based on its effectiveness in incorporating it into the organizational systems. According to the Sociotechnical Systems Theory, technology will not lead to better results by itself but has to be combined with human and organizational processes (Al Mamun and Uddin, 2025). Green HR practices turn the adoption of technology into behavioral change by providing employees with skills and motivation that enable them to use digital tools sustainably. Therefore, there is a mediation relationship between metaverse adoption and environmental performance through green HR practices.

H4: Green transformational leadership moderates the connection between green HR practices and firm environmental performance.

The Transformational Leadership theory asserts that leaders determine how effective the organizational practices are in performance outputs. Green transformational leaders strengthen environmental philosophy, inspire loyalty, and maintain the application of sustainability programs (Al Mamun et al., 2024). Green HR practices are better implemented and deliver more environmental results when leadership encouragement is high. Thus, it is hypothesized that green transformational leadership will play a positive moderating role between green HR practices and environmental performance by the firm (Figure 1).

3 Research methodology

The research article uses the quantitative research approach to test the relationships between metaverse adoption, green HR practices, green transformation leadership, and firm environmental

performance. By using this approach, the researcher can understand the influence of one variable on another and the direct and indirect effects of independent and mediator variables to dependent variable.

3.1 Research context and sampling justification

Saudi Arabia is a strategically prominent emerging economy that is in concurrent digital transformation and sustainability reform processes as part of Vision 2030. The state has also put in place a heavy investment in digital infrastructure, artificial intelligence, smart governance, and green economic diversification programs. Under this national transformation agenda, companies are increasingly supposed to match their online capacities with environmental sustainability goals. Riyadh was chosen as the center of interest due to the fact that it acts as the administrative, technological, and economic center of Saudi Arabia. Most of the top IT companies, digital innovation centers, and policy-based transformation projects are located in Riyadh. Being the location of the head offices of the largest enterprises and governmental bodies that have to introduce the digital strategy, Riyadh can offer a suitable and focused environment to investigate the connection between the digital transformation and the environmental performance.

The reason why the IT sector has been chosen is that it is at the center of facilitating the digital transformation across industries. IT companies are highly technological industries as opposed to traditional industries that have IT capabilities as auxiliary tools, which can be the main strategic resources in these companies. IT activities also involve high energy use in data centers, cloud services, and digital platforms, and therefore, environmental performance has become a more pressing issue. The investigation of the IT industry thus allows one to consider sustainability results in an environment where digital transformation is not only widespread but also integrated into the strategy.

The choice of HR managers as key informants was related to three major reasons:

- 1 Strategic visibility: HR managers have cross-functional knowledge of organizational practices, leadership behaviors, development of digital skills, and sustainability efforts.
- 2 Participation in transformation Processes: to transform digitally, the transcription of workforces and their reskilling, altering the structure, and adapting the culture of an organization is often required, as is commonly organized or enabled by HR departments.
- 3 Knowledge of leadership practices: Since sustainability-based

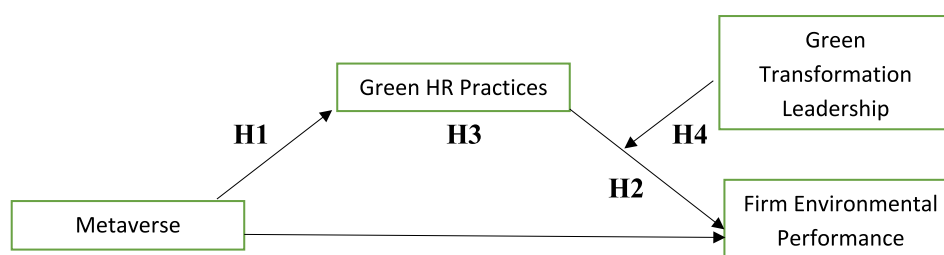


FIGURE 1
Theoretical model.

leadership affects employee behavior and the organizational culture, the HR managers are in a good position of evaluating green transformational leadership practices in organizations.

Earlier studies on organizational change and management often depend on the senior HR professionals as knowledgeable informants because of their general knowledge of the organizational systems.

To have data quality and relevancy, the following eligibility criteria were used:

- The respondents should be in an HR position of managerial level.
- Companies are forced to conduct business in Riyadh in the field of IT.
- Organizations should have been undertaking digital transformation activities for at least 2 years.
- The respondents should also be employees in an organization with a minimum of 3 years' experience so that they are familiar with the strategic initiatives.

A minimum of 50 employees has to be employed by firms to provide a structured management system. These requirements helped in making sure that the participants were relevant in terms of their knowledge and experience, to give informed responses on matters concerning digital transformation, practices of leadership, and environmental performance outcomes.

3.2 Data collection

The researcher uses the survey method to collect the data from HR managers working in the IT sector organizations located in Riyadh, KSA. The questionnaire was developed and distributed among the HR managers working in different organizations. The researcher distributed 325 questionnaires to the HR managers and received 303 responses. Out of the 303, a total of 277 responses are finalized to test the relationship among variables; 26 responses are missing values or filled by irrelevant persons. The final dataset used by the researcher was 277 responses.

3.3 Data analysis software

In this research, the analysis of the proposed conceptual model was done with the help of the Partial Least Squares Structural Equation Modelling (PLS -SEM) using SmartPLS (4.0). The choice of PLS-SEM was based on the fact that the study aims to test complex structural correlations with the presence of direct, mediating, and moderating effects. The proposed model includes several latent factors, terms of

interaction, and predictive relationships, which makes the use of variance-based SEM especially suitable. PLS-SEM has been selected due to the following four main reasons:

- The conceptual model contains the effects of mediation and moderation, and several interdependent relationships have to be estimated simultaneously. PLS-SEM is quite appropriate in treating such a complicated structure model.
- Predictive in nature: the study takes the view of a predictive perspective to explain variance in environmental performance. PLS-SEM is suggested in case the major aim is prediction and extension of theories instead of the strict confirmation of the theory.
- PLS-SEM is better than covariance-based SEM when the sample size is moderate, and they do not need large samples to obtain consistent estimates.
- PLS-SEM is not based on multivariate normality, and is suitable for survey data on organizations that do not follow a normal distribution.

3.4 Construct items

In this research article, four variables were used to test the relationships. Independent variable is metaverse adoption, which was adapted from the study by Dwivedi et al. (2022). Green HR practices was performing as a mediator variable, which was adapted from the study by Renwick et al. (2013). Firm environmental performance was a dependent variable, which was adapted from the study by Roscoe et al. (2019). Green transformation leadership was the only moderator that was adapted from the study by Chen and Chang (2013) (Table 1).

4 Data analysis

Table 2 depicts the demographic information of the data. The final dataset is 277 responses for testing the relationship. The indicator is about the gender of the respondents; 237 respondents are male, which means 85.50%, remaining 40 respondents are female, with the percentage of 14.50%. The second indicator represents the IT sector industries; 105 organizations belong to software houses with the percentage of 37.90%, 75 firms represent the IT services with the percentage of 27.00%, and 97 firms are related to database management with the percentage of 35.10%. The last column shows the experience level of the respondents; 48 respondents have 0–3 years of experience, with 17.32%, 173 respondents have 4–7 years of experience, with 62.45%, and 56 respondents have more than 7 years of experience, with 20.23%.

TABLE 1 Measurement constructs and items.

Construct	No. of items	Sample item	Source
Metaverse Adoption	3	We employ immersive training programs in the metaverse to upskill employees effectively.	Dwivedi et al. (2022)
Green HR Practices	6	Our recruitment process prioritizes candidates with environmental awareness and sustainability values.	Renwick et al. (2013)
Firm Environmental Performance	3	Our organization reduces energy and resource consumption effectively.	Roscoe et al. (2019)
Green Transformation Leadership	4	Leaders act as role models in practicing eco-friendly behavior.	Chen and Chang (2013)

4.1 Reliability of the data

Table 3 shows the values of Cronbach’s alpha, composite reliability, and average variance extracted (AVE). The minimum threshold values for Cronbach’s alpha are <0.7, which means poor internal consistency, 0.7–0.79 means acceptable internal consistency, 0.8–0.89 means good internal consistency, and more than 0.9 means excellent internal consistency. The value for composite reliability is 0.7 or higher, which means that measures are reliable and consistent. The value for average variance extracted (AVE) is 0.5 or higher, which means that variables explain 50% of the variance in their indicators.

Firm environmental performance has 0.711 Cronbach’s alpha, 0.718 composite reliability, and 0.562 average variance extracted (AVE) values. All three values are accepted and indicate the internal consistency. Green HR practices has 0.865 Cronbach’s alpha, 0.873 composite reliability, and 0.598 AVE. Green Transformation Leadership has 0.845 Cronbach’s alpha, 0.873 composite reliability, and 0.681 AVE. The metaverse adoption has 0.865 Cronbach’s alpha, 0.943 composite reliability, and 0.785 AVE values. All the constructs have reliable values.

4.2 Discriminant validity

Table 4 represents the values for discriminant validity. The rule of thumb is that the square root of AVE must be greater than the values shown in the same row and column for the off-diagonal correlation. The value of firm environmental performance is 0.750, which is greater than the other values, 0.143, 0.597, and 0.123. Green HR practices value is 0.773, which is also greater than other values as shown in the table. Green transformational leadership is 0.825, which is greater than other values. Metaverse adoption value is 0.886, which is greater than 0.123, 0.474, and 0.147.

HTMT was used to assess discriminant validity. Table 5 depicts that all HTMT values are less than the conservative value of 0.85, which is why it is concluded that the constructs have satisfactory discriminant validity. The highest value of HTMT was the one that compared firm environmental performance and green transformational leadership (0.642), which is within the acceptable limits. The other construct pairs show much lower HTMT ratios, which also support the empirical uniqueness of the constructs. These findings, therefore, suggest that the issues of multicollinearity and discriminant validity do not exist in the measurement model.

4.3 Structural model

The diagram of the structural model depicts the values of the items, R-square, and the change occurring in one variable due to other constructs. The independent variable is metaverse adoption, which has three items. The values for all three items are as follows: 0.871, 0.939, and 0.845. All values are acceptable. The mediating variable is green HR practices, which contains six items. The values of all items are as follows: 0.805, 0.719, 0.854, 0.795, 0.704, and 0.753. All the values are acceptable. Firm environmental performance is the dependent variable in the study. The variable has three items, and all the values are good. The last variable is Green Transformational Leadership, which is tested with the help of four items, and all the values are good and acceptable. H1 is measuring the direct effect of metaverse adoption toward the green HR practices which is positive and has the value of 0.474, which means that H1 is supported. H2 indicates the direct relationship of green HR practices to firm environmental performance, which has the value of 0.149, positive value means H2 is supported. H3 test the mediating role of green HR practices between metaverse adoption and firm environmental performance. The value –0.026 indicates the negative direct relationship between metaverse adoption and firm environmental performance.

TABLE 2 Demographics of the study.

Demographics	Details	Numbers	Ratio
Gender	Male	237	85.50%
	Female	40	14.50%
IT Sector Industries	Software House	105	37.90%
	IT Services	75	27.00%
	Database Management	97	35.10%
Experience	0–3 Years	48	17.32%
	4–7 Years	173	62.45%
	More than 7 Years	56	20.23%

TABLE 3 Construct reliability and validity.

Constructs	Cronbach’s alpha	Composite reliability (rho_a)	Average variance extracted (AVE)
Firm Environmental Performance	0.711	0.718	0.562
Green HR Practices	0.865	0.873	0.598
Green Transformation Leadership	0.845	0.873	0.681
Metaverse Adoption	0.865	0.943	0.785

TABLE 4 Discriminant validity Fornell–Larcker.

Constructs	Firm environmental performance	Green HR practices	Green transformation leadership	Metaverse adoption
Firm Environmental Performance	0.750			
Green HR Practices	0.143	0.773		
Green Transformation Leadership	0.597	0.022	0.825	
Metaverse Adoption	0.123	0.474	0.147	0.886

TABLE 5 Discriminant validity—HTMT.

Constructs	Firm environmental performance	Green HR practices	Green transformational leadership	Metaverse adoption
Firm Environmental Performance				
Green HR Practices	0.158			
Green Transformational Leadership	0.642	0.041		
Metaverse Adoption	0.136	0.512	0.166	

TABLE 6 Structural model results.

Hypothesis	Structural path	Path coefficient (β)	Result
H1	Metaverse Adoption → Green HR Practices	0.474	Supported
H2	Green HR Practices → Firm Environmental Performance	0.149	Supported
H3	Green HR Practices (Mediation Effect)	−0.026 (Direct Value)	Full Mediation
H4	Green Transformational Leadership (Moderation Effect)	0.086	Weak Moderation

TABLE 7 Coefficient of determination (R^2).

Construct	R^2 value	Interpretation
Green HR Practices	0.225	Moderate explanatory power
Firm Environmental Performance	0.380	Substantial explanatory power

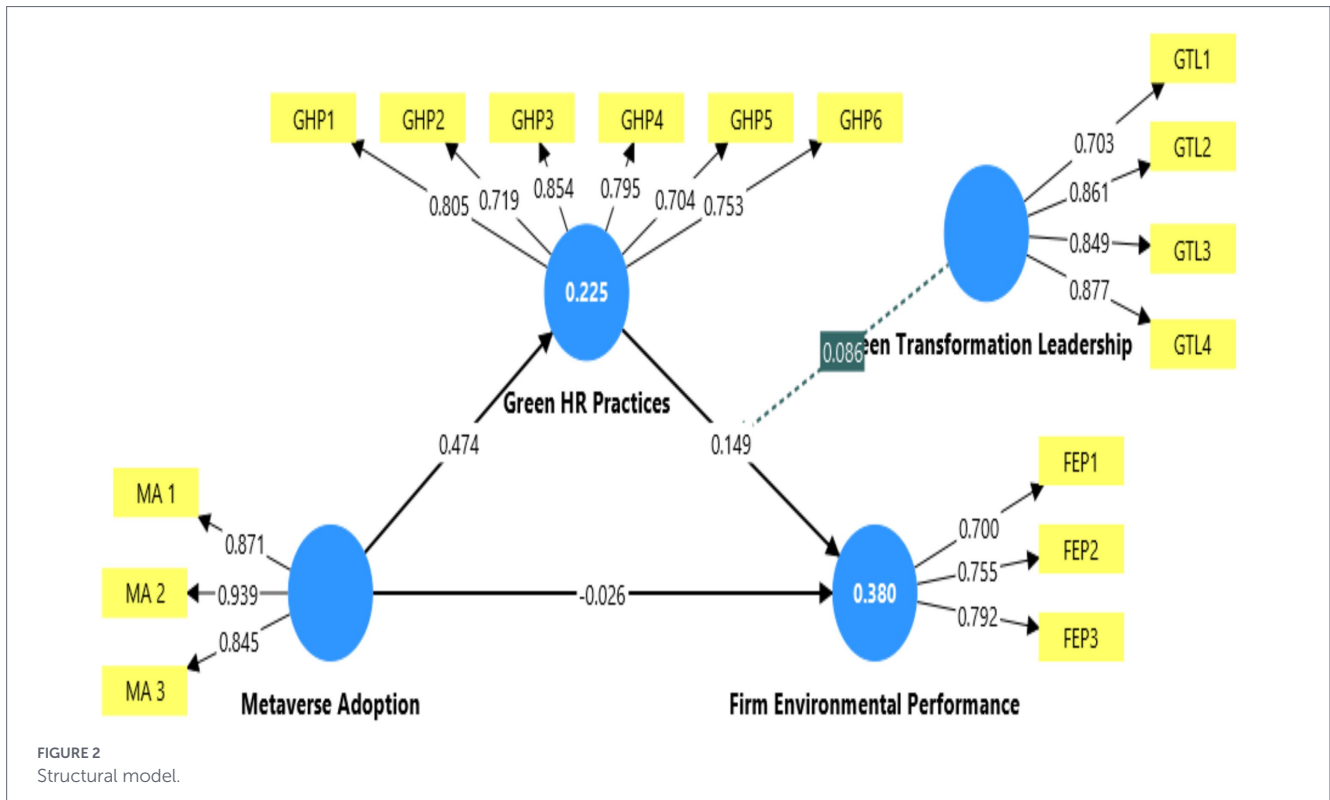
The overall model explains a significant portion of the variance in both the mediator, which is green HR practices, and the outcome variable, which is firm environmental performance. This means the theoretical framework metaverse adoption (Independent Variable), green HR practices (Mediator), and firm environmental performance (Dependent Variable), moderated by green transformational leadership, has good predictive validity and practical relevance.

However, the indirect effect is significant, which means that green HR practices mediate the relationship between metaverse adoption and firm environmental performance (Table 6).

H3 explains the full mediation and support. Metaverse adoption will not directly enhance the firm’s environmental performance; they need green HR policies to make it better. H4 is the moderating role of green transformation leadership between green HR practices and firm environmental performance. The value is 0.086, which indicates a less moderating effect, but the result is positive, meaning that H4 is supported as well. All the hypotheses of the study are supported, and the item values are acceptable (Table 7; Figure 2).

5 Discussion

The outcomes of H1 indicate that the implementation of metaverse technologies has a positive and statistically significant effect on the green human resource practices. This fact is supported by previous studies and argues that digital technologies can help optimize resources, decrease waste, and increase the level of environmental monitoring (Parry and Battista, 2023). Similar data have been presented by the European manufacturing companies and East Asian technology startups, where digitalization has increased carbon tracking and operational sustainability. Nevertheless, the current research builds on this body of literature in two important aspects. To begin with, the developed economies, which were mostly used as a sample in previous studies, are those with well-developed sustainability policies; in this case, digital transformation proves to be a way to increase the environmental performance in an emerging economy with a high pace of modernization, i.e., Saudi Arabia. Second, in the Saudi IT sector, in which digital capabilities are the key strategic resource, the environmental payoffs of digital transformation seem especially high due to the high intensity of the data infrastructure and the increased regulatory focus under Vision 2030. In turn, these findings contribute to the literature by showing that the effects of the digital transformation on the environment are not limited to Western settings; instead,



the same effects can be achieved in the framework of policy-driven digital transformations.

H2 suggests that there is a positive correlation between green human resource practices and environmental performance of the firm, which becomes relevant in accordance with the previous literature that suggests that green human resource programs increase both environmental performance and strategic alignment. As compared to the previous literature, in which sustainability is often discussed as a complex concept, the current findings emphasize the fact that environmental performance is a highly sensitive aspect of the Saudi IT environment (Tang et al., 2018). This could be indicative of an increasing government focus on environmental key performance indicators as part of the Vision 2030, where digital accountability systems become part of the targets of sustainability.

H3 validates the fact that green human resource practices are a mediation agent whereby organizational initiatives, such as metaverse adoption, are converted to sustainable performance. This observation supports the Dynamic Capabilities Theory that argues that companies need to rearrange resources to create performance consequences. Although the former literature usually assumes the linear connection between technology and performance, the current findings elucidate the mediating process: digital transformation reorganizes organizational processes, thus enhancing sustainability indicators. The mediation effect explains why some companies do not achieve sustainability returns even after investing in technologies; they might not be efficient enough in the transformation processes (Afsar et al., 2020). In the Saudi IT industry, in which the fast pace of development of digital infrastructure is state-led, digital transformation acts as the connection between strategic projects and effective environmental results.

The outcomes of H4 confirm that transformational leadership that is green enhances the relationship between environmental performance and digital transformation to a great extent. This observation is aligned with the research on the sustainability of leadership that indicates that eco-oriented leaders facilitate pro-environmental behavior and correlate the organizational values to the sustainability agenda (Chen and Chang, 2022). However, the present research contributes to the body of knowledge by demonstrating that the impact of leadership is not merely the direct relationship between them but also because it intensifies the efficiency of digital systems to generate environmental impacts. Meaning, it cannot be technology only. In the Saudi context, where casual and strict leadership hierarchies, combined with value-based management practices, are culturally relevant, the role of leadership orientation becomes especially important in the process of digital capabilities being translated into environmental action. The identified moderating effect seems to be stronger, as compared to the results found in Western or decentralized contexts, suggesting that leadership influence might be boosted in collectivist and high power-distance cultures. This observation also contributes to sustainability literature because it highlights leadership as a situational enhancer of the impacts of digital transformation.

6 Conclusion

The study aimed to explore how metaverse adoption affects environmental and sustainable performance in the information technology (IT) sector of Saudi Arabia, with the specific interest of the mediating effect of green HR practices. The article was based on the dynamic capability theory and the current

sustainability literature and aimed toward explaining the mechanisms and boundary conditions that make the digital initiatives transferable into measurable environmental advantages. The design was a quantitative research design, which used survey data as a source of information collected among human resource managers working in IT companies located in Riyadh, Saudi Arabia. The obtained data were performed on the Partial Least Squares Structural Equation Modeling (PLS-SEM) to determine the direct, mediating, and moderating relationships as established in the proposed Sustainable Digital Transformation Model.

Metaverse adoption was identified to improve the environmental performance and the overall sustainable performance of companies significantly. This finding confirms that digital technologies do not just serve as operational capabilities but also as strategic capabilities of sustainability, especially in highly digitized industries. Second, organizational initiatives are translated into sustainability outcomes using green HR practices as an enabling mediating factor. It is quite evident that sustainability gains do not emerge through isolated technological investment; instead, they become manifested in a form of green HR practices that restructure organizational routine and capability. Third, green transformational leadership was revealed to have a moderating contribution to the metaverse adoption effects on firm sustainable performance. This observation highlights the reality that leadership orientation is an essential prerequisite, within the Saudi environment, where hierarchical lines and culturally oriented management are major characteristics. In conclusion, this study notes that the interactions between technological change, organizational capacity, and leadership orientation are key to sustainable performance in new digital economies.

6.1 Theoretical and practical contributions

In theory, this study contributes to sustainability research because it combines metaverse adoption and green HR practices in the context of a dynamic capability framework and offers a more mechanism-based explanation of firm sustainable performance. To provide empirical evidence, it provides evidence based on the IT sector in Saudi Arabia, which is a largely under-researched and strategically significant emerging digital sector in policy-oriented transition under Vision 2030. In practice, the study shows that companies seeking to achieve better environmental results have to invest in digital infrastructure as well as in the alignment of leadership and development of organizational capabilities.

6.2 Limitations and future research directions

This research article has a number of limitations that also offer future research opportunities. First, the sample has been narrowed down to the information technology sector, which might diminish the results in generalizability. Future studies ought to generalize the proposed model in other non-service sectors, such as manufacturing, to increase external validity and criticize sector-specific dynamics. Second, the current model focuses on the

adoption of the metaverse, green human resource, green transformational leadership, and performance on the environment. To make the framework more comprehensive, future studies can extend the framework to include more elements of organizations, such as the integration of supply chain, customer orientation, and product innovation, to make the results of sustainability more all-encompassing.

Third, other typologies of leadership, including servant leadership, responsible leadership, or ethical leadership, might be examined as potential moderators or antecedents in the model. The comparison between various leadership strategies can bring a better understanding of the situational factors that maximize the effectiveness of sustainability projects. Fourth, the research design used in the study was cross-sectional. Further research might use quasi-longitudinal or longitudinal data to more stringently test the causal relationships between metaverse adoption and green HR practices and sustainability outcomes. The longitudinal designs would also enable the researcher to get the dynamic change of digital transformation and environmental performance over time. Finally, other mediating variables can be added, including green innovation, employee green behavior, and organizational learning, to come up with a more detailed model that explains the effect of metaverse adoption on the environmental performance. Such studies across national boundaries or across multiple industries would provide an even stronger foundation and external validity of the results.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the (patients/participants or patients/participants legal guardian/next of kin) was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

MT: Writing – review & editing, Resources, Conceptualization, Funding acquisition, Writing – original draft, Project administration, Investigation, Methodology, Supervision, Validation, Software, Formal analysis, Data curation, Visualization. FA: Writing – review & editing, Resources, Funding acquisition, Validation, Software, Formal analysis, Data curation.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Correction note

This article has been corrected with minor changes. These changes do not impact the scientific content of the article.

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