



# Framing carbon pricing for public acceptance: an integrated implementation perspective on sustainability perceptions in an emerging economy

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## Abstract

Carbon pricing is increasingly recognised as a cornerstone of national sustainability strategies, yet its long-term success depends not only on sound policy design but also on how implementation is perceived by the public. Despite growing research on public acceptance of carbon pricing, limited attention has been given to how implementation characteristics shape multidimensional sustainability evaluations in emerging economies. To address this gap, this study integrates Diffusion of Innovation (DOI) theory with the Triple Bottom Line (TBL) framework to examine the associations between innovation attributes and perceptions of economic feasibility, social legitimacy, and environmental credibility. Using survey data from Malaysia ( $n=918$ ), multiple regression analyses and diagnostic assessments reveal substantial interdependence among DOI attributes, suggesting that implementation characteristics may operate as an integrated perception structure rather than being evaluated as entirely independent implementation mechanisms. The findings indicate consistently positive associations between DOI-based implementation characteristics and perceived economic, social, and environmental sustainability outcomes, reflecting an integrated pattern of public policy evaluation. The observed multicollinearity, strong intercorrelations, and principal component analysis further suggest that respondents' evaluations may reflect an integrated perception of implementation quality rather than completely separable evaluations of individual mechanisms. The study contributes to diffusion and sustainability policy research by demonstrating how integrating DOI and TBL offers a more comprehensive perspective on public evaluations of carbon pricing implementation. The findings highlight the importance of coherent implementation strategies incorporating pilot implementation, policy communication, transparency, and complementary governance mechanisms to strengthen policy legitimacy in emerging economies.

**Keywords** Carbon pricing · Public acceptance · Diffusion of innovation (DOI) · Triple bottom line (TBL) · Sustainability perceptions · Policy implementation mechanisms

## 1 Introduction

Carbon pricing has emerged as a key environmental policy instrument for mitigating greenhouse gas emissions and facilitating low-carbon transitions through market-based regulatory mechanisms (The World Bank 2024). While

substantial research has focused on the economic efficiency and technical design of carbon pricing systems, increasing evidence suggests that policy effectiveness also depends on implementation feasibility, public legitimacy, and the perceived credibility of sustainability outcomes (Qazi et al. 2019). In many jurisdictions, carbon pricing initiatives have encountered implementation barriers related to perceived economic burden, fairness concerns, and uncertainty regarding environmental performance (Bachus et al. 2019; Maestre-Andrés et al. 2019; Zhang et al. 2023a). These challenges highlight the need for policy-oriented research examining how environmental policy design and implementation mechanisms are associated with societal evaluations of carbon pricing as a regulatory instrument.

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Existing studies have predominantly examined carbon pricing from fiscal, technological, or regulatory perspectives, often emphasising emissions reduction potential, compliance structures, and economic modelling outcomes (Ramalho and Santos 2021; Gaspar and Parry 2021). Although these contributions are critical for policy development, comparatively less attention has been paid to how interacting implementation mechanisms, such as pilot deployment, perceived policy complexity, and outcome transparency, are associated with perceived sustainability performance and policy feasibility (Faiers et al. 2007; Ahmad et al. 2023). Moreover, prior research frequently investigates acceptance through isolated constructs such as trust or distributive fairness (Zhang et al. 2023a), rather than analysing how multiple interconnected policy design features are associated with economic feasibility, social legitimacy, and environmental credibility simultaneously. Furthermore, although previous studies have examined public acceptance of carbon pricing, they have rarely integrated Diffusion of Innovation (DOI) theory with the Triple Bottom Line (TBL) framework to explain how policy implementation characteristics shape multidimensional sustainability evaluations. Consequently, the theoretical mechanisms linking innovation attributes to economic, social, and environmental policy perceptions remain insufficiently developed. In complex governance contexts, stakeholders may form holistic judgments of implementation quality, where multiple policy design attributes are cognitively integrated into broader evaluative perceptions. This perspective aligns with systems-oriented research suggesting that policy implementation in emerging economies is shaped by interconnected institutional and governance conditions rather than isolated policy characteristics (Siankwilimba et al. 2025). Addressing this gap is important because policy implementation involves multiple governance mechanisms that may jointly influence public evaluations of environmental, social, and economic sustainability, particularly in emerging economies where carbon pricing remains at an early stage of policy development.

In transitional policy environments where carbon pricing remains relatively novel, public evaluation is likely influenced not only by expected policy outcomes but also by the experiential and observable characteristics of policy implementation. Mechanisms such as phased deployment, demonstrable environmental outcomes, and understandable regulatory structures may function as critical governance tools in strengthening policy credibility and long-term adoption capacity. Rather than being evaluated entirely independently, these implementation characteristics may collectively contribute to an integrated perception of policy implementation quality. Malaysia provides a relevant empirical setting for examining these dynamics. As a rapidly industrialising emerging economy pursuing carbon

intensity reduction targets and exploring market-based climate instruments, including voluntary carbon markets and potential carbon taxation, Malaysia represents a policy transition context in which implementation design and public legitimacy are likely to shape the durability of future environmental regulation.

To address these gaps, this study develops an Experiential Environmental Policy Implementation Framework by integrating DOI theory with the TBL framework. Rather than treating DOI attributes solely as determinants of innovation adoption, the proposed framework reconceptualises them as implementation mechanisms through which stakeholders evaluate the economic, social, and environmental performance of carbon pricing policies. These attributes are examined in relation to three sustainability evaluation dimensions, such as economic, social, and environmental, derived from the Triple Bottom Line (TBL) perspective. While analytically distinct, the framework recognises that these implementation attributes may exhibit substantial interdependence in practice. Although conceptually distinguishable within DOI theory, these implementation mechanisms may be cognitively evaluated as an integrated perception structure in respondents' assessments of carbon pricing implementation. Using survey data from Malaysia, the study examines the associations between implementation mechanisms and multidimensional sustainability evaluations while exploring whether their empirical relationships reflect a broader perception of implementation quality.

This research contributes to the environmental policy literature in four ways. First, it extends the application of Diffusion of Innovation (DOI) theory by repositioning innovation attributes as policy implementation mechanisms that shape public evaluations of carbon pricing, rather than focusing solely on innovation adoption. Second, it integrates the DOI theory with the Triple Bottom Line (TBL) framework to provide a multidimensional perspective on how implementation characteristics are associated with economic, social, and environmental sustainability perceptions. Third, the study contributes to sustainability governance research by showing that public evaluations of carbon pricing may reflect an integrated implementation-quality perception, suggesting that implementation characteristics should not always be interpreted as completely independent dimensions. Finally, the study provides evidence from Malaysia on how integrated implementation considerations may inform strategies for strengthening the legitimacy of carbon pricing in emerging economies.

## 2 Literature review

### 2.1 Diffusion of innovation (DOI) theory and environmental policy implementation

Rogers' (2003) Diffusion of Innovation (DOI) theory identifies five attributes influencing the adoption of innovations: relative advantage, compatibility, complexity, trialability, and observability. Although originally developed in technological and organisational adoption contexts, DOI has increasingly been applied to public policy innovation, including environmental policy instruments such as carbon pricing (Khan et al. 2022; Thirakulwanich et al. 2025). Within environmental governance research, these attributes can be interpreted not only as psychological perceptions but also as features of policy implementation and communication that influence how citizens evaluate regulatory interventions. Although DOI conceptualises these attributes as conceptually distinct dimensions (Rogers 2003), empirical studies in governance and sustainability contexts frequently report substantial correlations among them, suggesting that stakeholders may not always evaluate implementation characteristics independently. A primary example of this occurs in the assessment of complex, process-based innovations (Greenhalgh et al. 2004). In such cases, stakeholders tend to form a holistic judgment rather than a granular, attribute-by-attribute analysis. This pattern is consistent with the halo effect (Nisbett and Wilson 1977; Feeley 2002), whereby an overall impression of a regulatory intervention may influence evaluations of its individual characteristics.

Relative advantage refers to the extent to which a policy is perceived to provide benefits relative to existing arrangements (Zijlstra et al. 2020). Studies show that perceived economic efficiency (Budolfson et al. 2021; Hao et al. 2020) and environmental improvements such as air quality enhancement (Chung et al. 2018; Maradin 2021) contribute to favourable evaluations of climate policy instruments. Compatibility represents the degree to which policies align with prevailing societal values, institutional arrangements, and sustainability priorities (Jansson 2011; Rogers et al. 2014). When policies resonate with expectations of fairness, distributive justice, and national development goals, perceived legitimacy and acceptance tend to increase (Elmoustapha et al. 2018; Zhang et al. 2023a).

Complexity reflects the perceived difficulty of understanding policy design and operational mechanisms (Rogers et al. 2014; Al-Rahmi et al. 2021). Research indicates that complex regulatory structures, such as emissions trading or revenue recycling mechanisms, may reduce perceived fairness or policy comprehension if not clearly communicated (Guo et al. 2021; Liu et al. 2025; Fesenfeld 2025). Trialability refers to opportunities for incremental or experimental

exposure to policy mechanisms through pilot programmes or phased implementation (Münzel et al. 2020; Alam et al. 2021). Such approaches may allow individuals to better understand policy impacts and reduce uncertainty (Chen et al. 2021a). Observability captures the extent to which policy outcomes are visible, including environmental improvements or transparent use of revenues (Saidi et al. 2021; Mahajan et al. 2021). Observable outcomes can enhance trust in environmental regulation when impacts are clearly communicated and verifiable (Chen et al. 2021a). Collectively, these attributes provide a useful framework for examining how implementation design, communication, and governance processes influence public evaluations of environmental policy (Song et al. 2021; XuFeng & Hui, 2018). Instead of treating these attributes as entirely independent components, this study examines whether their empirical relationships are consistent with an integrated perception of implementation quality while recognising that they remain conceptually distinguishable within DOI theory.

### 2.2 Triple bottom line (TBL) framework and sustainability policy evaluation

The Triple Bottom Line (TBL) framework emphasises economic, social, and environmental dimensions of sustainability (Elkington 1997). Although initially developed in corporate sustainability contexts, TBL has been widely applied to public policy evaluation where multiple stakeholder outcomes must be considered simultaneously (Fauzi et al. 2010; Høgevoid et al. 2015). In climate policy research, multidimensional evaluation is particularly important because policy legitimacy often depends on perceived impacts across financial, societal, and environmental domains.

In the literature, economic perceptions relate to affordability, household cost implications, industrial competitiveness, and opportunities for green economic development (Povitkina et al. 2021). Negative economic perceptions often arise from concerns about increased energy costs or employment impacts (Vona 2019), while positive perceptions may emerge when policies are associated with innovation, investment, or long-term economic resilience (Bachus et al. 2019). Social perceptions focus on fairness, equity, transparency, and the inclusion of affected communities in policy processes (Maestre-Andrés et al. 2021; Sommer et al. 2022). Environmental perceptions relate to expectations regarding emission reductions, environmental protection, and associated public health benefits (Brand 2016; Merten et al. 2022).

Recent research suggests that climate policy support is shaped by how individuals evaluate policies across these interconnected sustainability dimensions rather than

through single-factor considerations (Ahonen et al. 2025). As such, TBL provides a useful analytical structure for capturing multidimensional policy evaluation outcomes in studies examining public responses to environmental regulation. However, despite the widespread application of the TBL framework in sustainability assessment, relatively few studies have explicitly linked multidimensional sustainability evaluation with innovation implementation mechanisms. Therefore, integrating TBL with DOI provides a complementary theoretical perspective for explaining how implementation characteristics shape public evaluations of carbon pricing policies.

### 2.3 Innovation attributes and public evaluation of environmental policies

Empirical research on sustainability policies and environmental innovations demonstrates that innovation-related attributes play a significant role in shaping public evaluations and behavioural responses. Studies on renewable energy adoption, energy efficiency programmes, and environmental technologies show that perceived benefits and value alignment enhance support, while perceived complexity may reduce engagement (Hao et al. 2020; Zhang et al. 2020; Pan et al. 2023). Exposure to pilot initiatives or visible environmental improvements has been associated with greater public trust and reduced uncertainty regarding sustainability policies (Sunstein 2014; Chen et al. 2021a).

In carbon pricing research, several determinants of public evaluation have been identified, including fairness perceptions, transparency of revenue use, and policy clarity (Sunstein 2014; Chen et al. 2021a). Clearly communicated revenue recycling mechanisms and equitable distribution of policy impacts have been shown to strengthen policy support, whereas perceived cost burdens or opaque governance processes may undermine acceptance (Bachus et al. 2019; Maestre-Andrés et al. 2019). Evidence from Malaysia suggests that institutional accountability and perceived responsibility influence public evaluation of carbon taxation more strongly than generalised trust in government (Muhammad et al. 2022).

Policy awareness and literacy also influence how individuals interpret environmental regulation (Carattini et al. 2019; Huber et al. 2020). Greater understanding of policy mechanisms is associated with more nuanced evaluations of economic and environmental outcomes, whereas limited familiarity may amplify concerns about complexity or uncertainty. Despite these insights, existing studies have generally examined these determinants independently, providing limited understanding of how multiple implementation characteristics collectively shape public evaluations of environmental policy. This suggests an opportunity to

examine whether citizens integrate different implementation characteristics into a broader perception of implementation quality when evaluating carbon pricing.

### 2.4 Interdependence of innovation attributes in environmental policy evaluation

Although DOI attributes are conceptually distinct, previous studies suggest that stakeholders may evaluate these implementation characteristics in an interconnected manner when assessing complex environmental policies (Greenhalgh et al. 2004; Liu et al. 2025; Fesenfeld 2025). When policy instruments involve regulatory design, communication transparency, and institutional credibility, citizens may form holistic evaluative judgments in which perceived performance, clarity, alignment, and visibility are cognitively integrated. Some studies have suggested that strong correlations among innovation attributes may indicate that stakeholders develop a broader perceptions of implementation quality. However, existing evidence remains largely indirect because most studies have not explicitly tested higher-order measurement structures using latent-variable approaches. Consequently, high intercorrelations among DOI attributes should be interpreted cautiously. They may reflect shared cognitive evaluations of policy implementation, conceptual proximity among constructs, or methodological characteristics of survey-based perception research. Accordingly, the present study examines the associations between implementation mechanisms and sustainability evaluations while considering whether these relationships collectively reflect an integrated perception of implementation quality. This interpretation is treated as a theoretical implication to be evaluated, rather than an assumption established *a priori*.

### 2.5 Integrated conceptual framework and hypotheses

Building on Rogers' Diffusion of Innovation (DOI) theory (Rogers 2003) and the Triple Bottom Line (TBL) framework (Elkington 1997), this study develops an integrated conceptual framework to examine how citizens evaluate carbon pricing as an environmental policy innovation in Malaysia. DOI identifies five attributes such as relative advantage, compatibility, complexity, trialability, and observability that influence how individuals interpret the characteristics and implementation features of new policy instruments (Khan et al. 2022; Thirakulwanich et al. 2025). Complementing this perspective, the TBL framework captures multidimensional sustainability evaluation domains, including economic, social, and environmental perceptions (Fauzi et al. 2010; Høgevold et al. 2015).

In the context of environmental policy, DOI attributes are interpreted as reflecting policy implementation mechanisms rather than abstract technological features alone. Specifically, Relative Advantage (RA) is interpreted as Expected Policy Performance, Compatibility (C) as Socioeconomic Alignment, Complexity (CX) as Perceived Policy Complexity, Trialability (TR) as Pilot-Based Implementation, and Observability (OB) as Outcome Transparency. Correspondingly, the TBL dimensions represent policy evaluation outcomes, including Economic (ED) as Economic Feasibility, Social (SD) as Social Legitimacy, and Environmental (ENV) as Environmental Credibility. This interpretive positioning maintains theoretical consistency while situating DOI–TBL relationships within an environmental governance and policy evaluation context. The theoretical integration of DOI and TBL positions innovation attributes as implementation mechanisms associated with citizens’ multidimensional evaluations of carbon pricing, thereby providing a theoretical bridge between policy implementation processes and sustainability evaluation outcomes. This bridge underscores that carbon pricing implementation represents an evolving governance process in which public perceptions provide important evidence for understanding policy evaluation and informing future implementation considerations. Conceptualising public evaluation as a dynamic input for governance rather than a final endpoint allows the integrated framework to capture the continuous interplay between policy execution and societal response.

The conceptual framework treats the five DOI attributes as conceptually distinct implementation mechanisms derived from DOI theory and examines their relationships with three multidimensional sustainability evaluation outcomes. At the same time, the framework recognises that strong empirical relationships among these attributes, if observed, may indicate broader perceptions of implementation quality. This possibility is explored through supplementary diagnostic analyses and interpreted cautiously as a theoretical implication rather than a formally specified higher-order construct. Based on the integrated framework, the following hypotheses are proposed:

Economic Policy Evaluation (Economic Feasibility, ED):

**H1a** *Expected Policy Performance (RA) is significantly associated with economic feasibility.*

**H1b** *Socioeconomic Alignment (C) is significantly associated with economic feasibility.*

**H1c** *Perceived Policy Complexity (CX) is associated with economic feasibility.*

**H1d** *Pilot-Based Implementation (TR) is significantly associated with economic feasibility.*

**H1e** *Outcome Transparency (OB) is significantly associated with economic feasibility.*

Social Policy Evaluation (Social Legitimacy, SD):

**H2a** *Expected Policy Performance (RA) is significantly associated with social legitimacy.*

**H2b** *Socioeconomic Alignment (C) is significantly associated with social legitimacy.*

**H2c** *Perceived Policy Complexity (CX) is associated with social legitimacy.*

**H2d** *Pilot-Based Implementation (TR) is significantly associated with social legitimacy.*

**H2e** *Outcome Transparency (OB) is significantly associated with social legitimacy.*

Environmental Policy Evaluation (Environmental Credibility, ENV):

**H3a** *Expected Policy Performance (RA) is significantly associated with environmental credibility.*

**H3b** *Socioeconomic Alignment (C) is significantly associated with environmental credibility.*

**H3c** *Perceived Policy Complexity (CX) is associated with environmental credibility.*

**H3d** *Pilot-Based Implementation (TR) is significantly associated with environmental credibility.*

**H3e** *Outcome Transparency (OB) is significantly associated with environmental credibility.*

Figure 1 illustrates the hypothesised first-order relationships between DOI implementation mechanisms and TBL evaluation outcomes. The integrated implementation-quality perception is interpreted as an emergent empirical pattern rather than a formally specified latent construct and is therefore not represented as a separate construct within the conceptual model.

## Policy Implementation Mechanisms

## Policy Evaluation Outcome

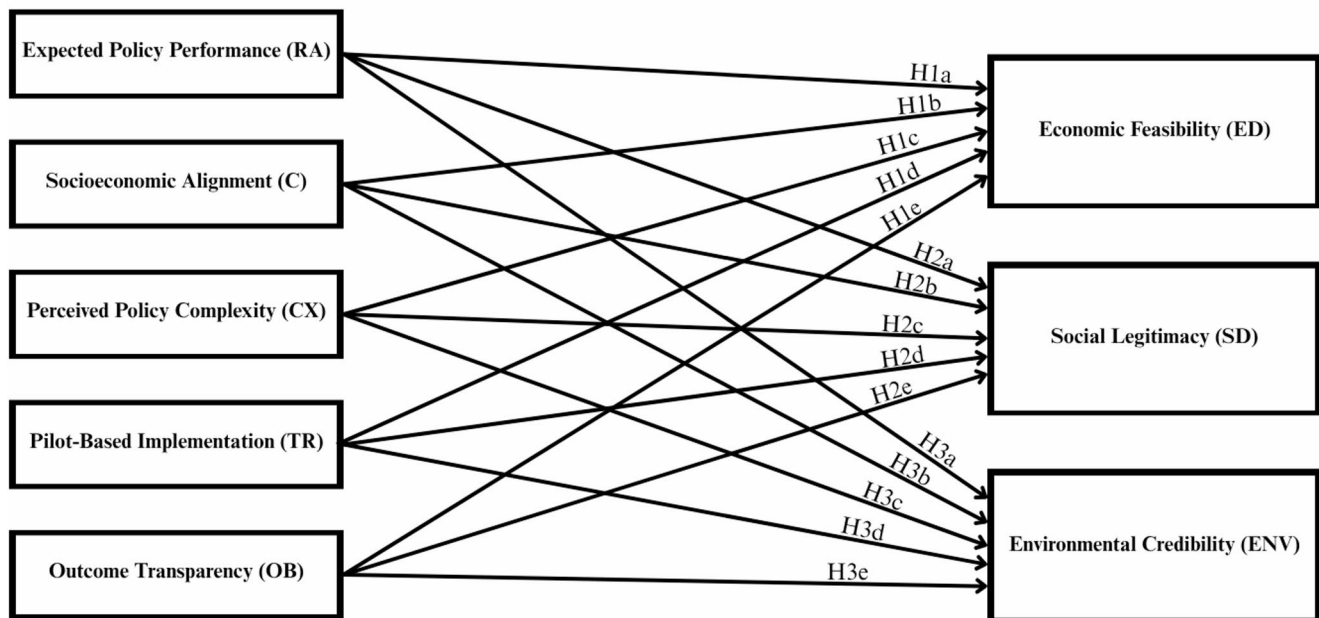


**Fig. 1** DOI-TBL conceptual framework for environmental policy evaluation. Policy implementation mechanisms represent conceptually distinct DOI attributes (RA, C, CX, TR, OB), while policy evaluation outcomes represent TBL dimensions (ED, SD, ENV) through which

citizens assess the economic, social, and environmental performance of carbon pricing. The empirical relationships among these implementation mechanisms may reflect an integrated perception of implementation quality in respondents' evaluations

### 3 Methodology

#### 3.1 Research design

This study employed a quantitative survey design to examine the relationships between the Diffusion of Innovation (DOI) attributes (Relative Advantage, Compatibility, Complexity, Trialability, and Observability) and public perceptions of the economic, social, and environmental dimensions of sustainability in the context of carbon pricing in Malaysia. The target population consisted of Malaysian residents aged 18 years and above, representing citizens who are directly or indirectly affected by energy pricing and carbon policy, providing policy-relevant insights for implementation and governance. Data were collected using an online questionnaire distributed through convenience sampling across multiple digital platforms to obtain responses from diverse socio-demographic groups throughout Malaysia. Although convenience sampling limits statistical generalisability, it is widely employed in exploratory studies examining public perceptions of emerging policy issues where probability sampling is difficult to implement. A total of 918 valid responses were obtained for analysis.

#### 3.2 Questionnaire development

The questionnaire was structured into three main sections. The first captured demographic information such as age, gender, education, income and many more. The second measured DOI factors, using scales adapted from Rogers and Shoemaker (1971), Tornatzky and Klein (1982), and subsequent applications in sustainability research (e.g., Zhang et al. 2015; Suk 2018). The third section focused on the Triple Bottom Line (TBL) framework, assessing economic, social, and environmental perceptions through items adapted from prior studies (Maestre-Andrés et al. 2019; Carley and Konisky 2020; Rashidi et al. 2022). Although the DOI attributes and TBL dimensions retain their original theoretical definitions, they are interpreted in this study as reflecting perceived policy implementation characteristics and multi-dimensional policy evaluation outcomes (economic feasibility, social legitimacy, and environmental credibility). All items were rated on a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree).

The questionnaire was reviewed by subject-matter experts to assess content validity prior to pilot testing. Minor wording revisions were subsequently made based on expert feedback and pilot responses to improve clarity and contextual relevance. The instrument was then pre-tested with 20 respondents to evaluate its clarity and internal

consistency before full deployment. Participation was voluntary and anonymous; respondents were informed of the study purpose prior to participation, and no personally identifiable information was collected. These procedures were intended to reduce evaluation apprehension, response bias, and the potential influence of common method bias associated with self-reported survey data. Completion of the questionnaire was taken as informed consent to participate in the study. This study received ethical approval from Universiti Malaysia Sarawak (UNIMAS) (Reference No. UNIMAS/NC-22.02/09–17(14)). The theoretical foundations of each construct were drawn from established studies in the DOI and sustainability policy literature. Measurement items were adapted and substantially modified to reflect the Malaysian carbon pricing context while preserving the underlying theoretical meaning of each construct. Following the measurement refinement process, the final questionnaire consisted of 15 DOI items (three items for each implementation mechanism) and 9 TBL items (three items for each sustainability dimension). The theoretical foundations and measurement development for each construct are summarised in Table 1.

### 3.3 Measurement refinement

The initial questionnaire contained 25 DOI items and 45 TBL items adapted from previous literature to ensure comprehensive construct coverage during instrument development. The measurement refinement process consisted of three stages. First, the initial pool of items was developed from the relevant literature to ensure comprehensive coverage of each construct. Second, subject-matter experts reviewed the items to evaluate their conceptual representativeness and contextual relevance. Third, pilot testing was conducted to assess item clarity and consistency, after which the most representative items for each construct

were retained for the final questionnaire. This refinement preserved the conceptual breadth of each construct while producing a parsimonious measurement instrument suitable for regression analysis. Consequently, three items were retained for each construct based on expert consensus regarding conceptual representativeness, clarity, contextual relevance, and construct coverage. Items that exhibited conceptual redundancy, ambiguous wording, or limited contextual relevance during expert review and pilot testing were excluded from the final instrument. Perceived Policy Complexity (CX) was operationalised using three retained items addressing the perceived understandability and complexity of carbon pricing and its implementation. The retained items were: CX1, “I believe the concept of carbon pricing is easy to understand”; CX2, “The implementation of carbon pricing is straightforward and clear”; and CX3, “Carbon pricing would be too complicated to implement in practice.”

### 3.4 Data analysis

The study included DOI attributes as the independent variables and TBL dimensions as the dependent variables. Demographic information was collected to describe the characteristics of the sample and to facilitate the interpretation of policy perceptions across respondent groups. Data analysis was conducted using SPSS. Descriptive statistics were used to profile respondents and summarize key variables (Nick 2007). Cronbach’s alpha tests were applied to assess the internal consistency of measurement scales (Osburn 2000). In particular, average variance extracted (AVE), the Fornell–Larcker criterion, and the heterotrait–monotrait (HTMT) ratio were not assessed in the present study. The Pearson correlation coefficient ( $r$ ) was calculated as:

**Table 1** Theoretical foundations and measurement development

| Construct          | References                                                                                                                                               | Measurement development                              |
|--------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------|
| Relative advantage | (Mutuku 2019; Duggal 2021; Han 2024; Digitemie and Ekemezie 2024)                                                                                        | Adapted and contextually modified for carbon pricing |
| Compatibility      | (Zhang et al. 2023b; Hui et al. 2023; Ahmad et al. 2023)                                                                                                 | Adapted and contextually modified                    |
| Complexity         | (Greenhalgh et al. 2017; Hsu et al. 2021; Irfan et al. 2021; Pan et al. 2023)                                                                            | Adapted and contextually modified                    |
| Trialability       | (Wang and Yi 2021; Chen et al. 2021b; Song et al. 2021; Liu et al. 2022)                                                                                 | Adapted and contextually modified                    |
| Observability      | (Romero-de-Diego et al. 2021; Almaiah et al. 2022; Köppl and Schratzenstaller 2023)                                                                      | Adapted and contextually modified                    |
| Economic           | (Bachus et al. 2019; Vona 2019; Dussaux 2020; Povitkina et al. 2021)                                                                                     | Adapted and contextually modified                    |
| Social             | (Savin et al. 2020; Maestre-Andrés et al. 2021; Sommer et al. 2022; Upham et al. 2023)                                                                   | Adapted and contextually modified                    |
| Environmental      | (Leroutier 2022; Suki et al. 2022; Yue et al. 2022; Uğur 2022; Anderson 2023; Climatetrade 2023; O’Regan and Nyhan 2023; Edward 2024; Savin et al. 2024) | Adapted and contextually modified                    |

$$r_{xy} = \frac{\sum (X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum (X_i - \bar{X})^2 \sum (Y_i - \bar{Y})^2}}$$

where  $X_i$  and  $Y_i$  represent individual scores for DOI and TBL variables, and  $\bar{X}$  and  $\bar{Y}$  denote their respective means.

Diagnostic checks for multicollinearity (VIF) were conducted to assess the stability of the regression estimates and to evaluate the empirical relationships among the DOI attributes. Given that policy implementation characteristics are conceptually related, the VIF results also informed the interpretation of potential overlap in respondents' implementation perceptions. The regression analyses were conducted to examine the pattern of associations among the theoretically derived implementation mechanisms rather than to compare the implementation mechanisms based on the magnitude of their regression coefficients.

Subsequently, multiple linear regression analyses were performed to examine the associations between DOI implementation attributes and each dimension of the TBL framework (Rosselló 2012). The models link theoretical DOI constructs to governance-relevant outcomes by assessing how perceived implementation attributes are associated with economic, social, and environmental evaluations. The models were specified as follows:

$$ED_i = \beta_0 + \beta_1(RA_i) + \beta_2(C_i) + \beta_3(CX_i) + \beta_4(TR_i) + \beta_5(OB_i) + \epsilon_i$$

$$SD_i = \beta_0 + \beta_1(RA_i) + \beta_2(C_i) + \beta_3(CX_i) + \beta_4(TR_i) + \beta_5(OB_i) + \epsilon_i$$

$$ENV_i = \beta_0 + \beta_1(RA_i) + \beta_2(C_i) + \beta_3(CX_i) + \beta_4(TR_i) + \beta_5(OB_i) + \epsilon_i$$

where  $ED_i$ ,  $SD_i$  and  $ENV_i$  represent the economic feasibility, social legitimacy, and environmental credibility scores for respondent  $i$ ;  $\beta_0$  is the intercept;  $\beta_1 - \beta_5$  represent the estimated regression coefficients for the DOI implementation attributes; and  $\epsilon_i$  denotes the error term.

This methodological approach enabled systematic examination of how perceived policy implementation characteristics relate to multidimensional sustainability evaluations while incorporating supplementary diagnostic analyses to support interpretation of the regression findings. The findings provide evidence to inform integrated implementation strategies encompassing communication, pilot implementation, transparency, and other complementary policy mechanisms that may strengthen the feasibility, legitimacy, and credibility of carbon pricing initiatives in emerging economies.

Furthermore, to assess the robustness of the regression models and address potential multicollinearity among DOI implementation attributes, leave-one-out regressions were conducted (Steinberger and Leeb 2016). In addition,

**Table 2** Policy implementation mechanisms

| DOI attribute      | Policy implementation interpretation |
|--------------------|--------------------------------------|
| Relative advantage | Expected policy performance (RA)     |
| Compatibility      | Socioeconomic alignment (C)          |
| Complexity         | Perceived policy complexity (CX)     |
| Trialability       | Pilot-based implementation (TR)      |
| Observability      | Outcome transparency (OB)            |

**Table 3** Policy evaluation outcomes

| TBL dimension | Policy evaluation outcome       |
|---------------|---------------------------------|
| Economic      | Economic feasibility (ED)       |
| Social        | Social legitimacy (SD)          |
| Environmental | Environmental credibility (ENV) |

principal component analysis (PCA) was conducted as an exploratory diagnostic procedure to examine whether substantial shared variance existed among the DOI attributes (Schreiber 2021). The PCA was conducted to explore whether the substantial shared variance among the DOI attributes was consistent with respondents evaluating these implementation mechanisms through an integrated perception of implementation quality despite their conceptual distinction within DOI theory.

## 4 Results

Before presenting descriptive statistics, it should be noted that the Diffusion of Innovation (DOI) attributes and Triple Bottom Line (TBL) dimensions are interpreted through a policy implementation lens. Specifically, DOI attributes are conceptualized as policy implementation mechanisms, and TBL dimensions as policy evaluation outcomes. The mappings are as follows (Tables 2 and 3):

These interpretations align the analysis with governance-relevant implications while retaining the original construct abbreviations for clarity and consistency.

### 4.1 Descriptive statistics and reliability

Descriptive statistics for the main constructs are presented in Table 4. The mean values ranged from 3.48 to 3.54, indicating moderately positive perceptions of both the policy implementation mechanisms and the sustainability evaluation outcomes. Standard deviations were relatively low (0.80–0.84), suggesting a reasonable degree of consistency in respondents' evaluations. Skewness values ranged from  $-0.14$  to  $-0.00$ , while kurtosis values ranged from  $-1.28$  to  $-1.12$ . All values fall within the commonly accepted thresholds of  $\pm 2$ , indicating no substantial deviations from normality (Hair 2009). These results suggest that the data satisfy distributional assumptions for subsequent parametric analyses.

**Table 4** Descriptive statistics of constructs ( $N=918$ )

| Construct | Mean | SD   | Skewness | Kurtosis |
|-----------|------|------|----------|----------|
| RA        | 3.50 | 0.84 | -10.02   | -11.14   |
| C         | 3.49 | 0.82 | -10.00   | -11.12   |
| CX        | 3.48 | 0.83 | -10.01   | -11.17   |
| TR        | 3.53 | 0.83 | -10.10   | -11.13   |
| OB        | 3.51 | 0.82 | -10.09   | -11.18   |
| ED        | 3.53 | 0.80 | -10.11   | -11.28   |
| SD        | 3.54 | 0.80 | -10.14   | -11.26   |
| ENV       | 3.52 | 0.81 | -10.07   | -11.28   |

Rounded mean, SD, Skewness and Kurtosis to 2 decimal places for readability

**Table 5** Cronbach's alpha ( $\alpha$ )

| Construct | Cronbach's alpha ( $\alpha$ ) |
|-----------|-------------------------------|
| RA        | 0.913                         |
| C         | 0.901                         |
| CX        | 0.902                         |
| TR        | 0.908                         |
| OB        | 0.900                         |
| ED        | 0.954                         |
| SD        | 0.959                         |
| ENV       | 0.960                         |
| Overall   | 0.925                         |

Reliability analysis was conducted to assess the internal consistency of all measurement scales. As shown in Table 5, the Cronbach's Alpha ( $\alpha$ ) values for all constructs exceeded the recommended threshold of 0.70 (Tavakol and Dennick 2011), indicating strong internal consistency. The DOI-derived policy implementation mechanisms demonstrated high reliability (RA  $\alpha=0.913$ ; C  $\alpha=0.901$ ; CX  $\alpha=0.902$ ; TR  $\alpha=0.908$ ; OB  $\alpha=0.900$ ), while TBL-derived policy evaluation outcomes were also highly reliable (ED  $\alpha=0.954$ ; SD  $\alpha=0.959$ ; ENV  $\alpha=0.960$ ). The overall instrument reliability was 0.925. Although several Cronbach's alpha coefficients exceeded 0.90, such values are not uncommon in perception-based policy research where multiple items capture closely related aspects of the same construct. Therefore, the reliability results indicate strong internal consistency and support the use of the scales in the subsequent analyses. While these findings provide evidence of internal

consistency, the present study did not employ confirmatory measurement techniques such as confirmatory factor analysis (CFA). Accordingly, construct validity and discriminant validity should be interpreted with appropriate caution and warrant further examination in future research.

## 4.2 Correlations and multicollinearity

Pearson correlation analysis (Table 6) indicated significant positive associations among all constructs ( $p < .01$ ), reflecting strong positive associations that are consistent with the proposed implementation framework (Sedgwick 2012). Correlation coefficients were relatively high ( $r = .882 - 0.958$ ), suggesting strong perceptual alignment among DOI-derived implementation attributes. The high correlations among DOI attributes suggest that respondents tended to report highly similar evaluations across policy implementation characteristics. Given that these attributes represent conceptually related implementation mechanisms, substantial empirical overlap is not unexpected and therefore warrants careful interpretation alongside the multicollinearity diagnostics presented below. In policy implementation contexts, respondents may tend to evaluate implementation attributes holistically rather than distinguishing between technical characteristics of innovation. This pattern is consistent with previous policy perception research suggesting that individuals often form overall evaluations of complex policy instruments based on multiple closely related implementation characteristics.

However, such high correlations raise potential concerns regarding multicollinearity. Instead of indicating a flaw in the theoretical framework, these findings motivated additional diagnostic analyses to examine whether respondents evaluated the conceptually distinct implementation mechanisms through an integrated perception of implementation quality. Accordingly, robustness analyses were conducted to evaluate the stability of the regression estimates under alternative analytical conditions.

**Table 6** Correlations among variables

| Variable | RA_<br>Mean | C_<br>Mean | CX_<br>Mean | TR_<br>Mean | OB_<br>Mean | ED_<br>Mean | SD_<br>Mean | ENV_<br>Mean |
|----------|-------------|------------|-------------|-------------|-------------|-------------|-------------|--------------|
| RA_Mean  | 1           |            |             |             |             |             |             |              |
| C_Mean   | 0.908**     | 1          |             |             |             |             |             |              |
| CX_Mean  | 0.901**     | 0.903**    | 1           |             |             |             |             |              |
| TR_Mean  | 0.882**     | 0.898**    | 0.892**     | 1           |             |             |             |              |
| OB_Mean  | 0.903**     | 0.904**    | 0.914**     | 0.908**     | 1           |             |             |              |
| ED_Mean  | 0.910**     | 0.915**    | 0.915**     | 0.926**     | 0.930**     | 1           |             |              |
| SD_Mean  | 0.902**     | 0.907**    | 0.909**     | 0.928**     | 0.923**     | 0.956**     | 1           |              |
| ENV_Mean | 0.923**     | 0.922**    | 0.926**     | 0.927**     | 0.939**     | 0.958**     | 0.949**     | 1            |

\*\*Correlation is significant at the 0.01 level (2-tailed)

**Table 7** Regression results of DOI factors on TBL dimensions

| DV (TBL dimension) | Model $R^2$ | Significant regression coefficients ( $\beta$ , $p < .05$ )              | Statistical hypothesis result   |
|--------------------|-------------|--------------------------------------------------------------------------|---------------------------------|
| ED                 | 0.920       | RA (0.150***), C (0.147***), CX (0.141***), TR (0.297***), OB (0.263***) | H1a–H1e statistically supported |
| SD                 | 0.911       | RA (0.128***), C (0.125***), CX (0.141***), TR (0.358***), OB (0.242***) | H2a–H2e statistically supported |
| ENV                | 0.935       | RA (0.185***), C (0.133***), CX (0.175***), TR (0.237***), OB (0.277***) | H3a–H3e statistically supported |

\*\*\* $p < .001$ **Table 8** Multicollinearity diagnostics of DOI attributes

| Variable | Tolerance | VIF   |
|----------|-----------|-------|
| RA       | 0.127     | 7.901 |
| C        | 0.118     | 8.500 |
| CX       | 0.118     | 8.443 |
| TR       | 0.134     | 7.475 |
| OB       | 0.107     | 9.330 |

RA, expected policy performance; C, socioeconomic alignment; CX, perceived policy complexity; TR, pilot-based implementation; OB, outcome transparency

### 4.3 Multiple regression results

Multiple regression analyses were conducted to examine the associations between DOI-derived policy implementation mechanisms and TBL-based sustainability evaluation outcomes. The regression results are summarised in Table 7.

For economic feasibility (ED), the model explained 92.0% of the variance ( $R^2 = 0.920$ ,  $p < 0.001$ ). All five implementation mechanisms were positively and significantly associated with economic feasibility.

For social legitimacy (SD), the model explained 91.1% of the variance ( $R^2 = 0.911$ ,  $p < 0.001$ ). All five implementation mechanisms were positively and significantly associated with social legitimacy.

For environmental credibility (ENV), the model accounted for 93.5% of the variance ( $R^2 = 0.935$ ,  $p < 0.001$ ). All five implementation mechanisms were positively and significantly associated with environmental credibility.

The exceptionally high  $R^2$  values observed across the three regression models may partly reflect the close conceptual relationship between DOI implementation characteristics and multidimensional sustainability evaluation outcomes. Accordingly, the reported explanatory power should be interpreted as indicating substantial conceptual and empirical overlap between the DOI implementation attributes and the sustainability evaluation outcomes rather than solely exceptionally strong model fit.

Multicollinearity diagnostics were conducted to evaluate whether the high correlations among the DOI attributes affected the stability of the regression models. As shown in Table 8, tolerance values ranged from 0.107 to 0.134, while VIF values ranged from 7.475 to 9.330. Although these VIF values indicate substantial shared variance among the

DOI implementation attributes, they remain below the commonly applied threshold of 10 (O'Brien 2007). Hence, the regression estimates should be interpreted with appropriate caution, particularly given the conceptual proximity among the DOI implementation attributes.

Despite the elevated intercorrelations, all DOI implementation mechanisms remained statistically significant across the three regression models, and the direction of the estimated coefficients was theoretically consistent. However, given the substantial shared variance among the implementation mechanisms, the individual coefficients should not be interpreted as evidence of clear empirical separation or definitive differences in substantive importance.

### 4.4 Robustness and sensitivity analyses

Given the high intercorrelations among DOI attributes identified in Sect. 4.2 and the elevated VIF values reported in Table 8, additional robustness analyses were conducted to examine whether the principal regression findings remained stable under alternative analytical conditions.

First, leave-one-out regressions were performed, in which each DOI implementation attribute was sequentially removed from the regression models predicting economic feasibility (ED), social legitimacy (SD), and environmental credibility (ENV). Across all models, the  $R^2$  values remained consistently high (ED: 0.908–0.918; SD: 0.894–0.910; ENV: 0.927–0.934), and all regression models remained statistically significant ( $p < .001$ ). Across the alternative model specifications, the overall pattern of associations remained stable despite the high correlations among the DOI implementation attributes.

Second, principal component analysis (PCA) was conducted as an exploratory diagnostic procedure to examine the extent of shared variance among the DOI attributes. A single principal component accounted for the majority of the variance, with factor loadings ranging from 0.955 to 0.965. This result is consistent with the interpretation that respondents evaluated the DOI implementation mechanisms through an integrated perception of implementation quality. However, the PCA was not intended to establish a formal higher-order latent construct, and therefore these findings should be interpreted as exploratory evidence of substantial perceptual overlap rather than conclusive confirmation of

**Table 9** Robustness and sensitivity analyses of DOI implementation attributes

| Dv  | Analysis          | Implementation attribute removed/<br>method | $R^2$ | P-Value | Notes                                               |
|-----|-------------------|---------------------------------------------|-------|---------|-----------------------------------------------------|
| ED  | Leave-one-out     | RA                                          | 0.917 | <0.001  | All remaining implementation attributes significant |
| ED  | Leave-one-out     | C                                           | 0.917 | <0.001  | All remaining implementation attributes significant |
| ED  | Leave-one-out     | CX                                          | 0.918 | <0.001  | All remaining implementation attributes significant |
| ED  | Leave-one-out     | TR                                          | 0.908 | <0.001  | All remaining implementation attributes significant |
| ED  | Leave-one-out     | OB                                          | 0.913 | <0.001  | All remaining implementation attributes significant |
| ED  | PCA/factor score  | Component 1                                 | 0.917 | <0.001  | Exploratory DOI factor score                        |
| SD  | Leave-one-out     | RA                                          | 0.909 | <0.001  | All remaining implementation attributes significant |
| SD  | Leave-one-out     | C                                           | 0.910 | <0.001  | All remaining implementation attributes significant |
| SD  | Leave-one-out     | CX                                          | 0.909 | <0.001  | All remaining implementation attributes significant |
| SD  | Leave-one-out     | TR                                          | 0.894 | <0.001  | All remaining implementation attributes significant |
| SD  | Leave-one-out     | OB                                          | 0.905 | <0.001  | All remaining implementation attributes significant |
| SD  | PCA/factor score  | Component 1                                 | 0.907 | <0.001  | Exploratory DOI factor score                        |
| ENV | Leave-one-out     | RA                                          | 0.931 | <0.001  | All remaining implementation attributes significant |
| ENV | Leave-one-out     | C                                           | 0.933 | <0.001  | All remaining implementation attributes significant |
| ENV | Leave-one-out     | CX                                          | 0.932 | <0.001  | All remaining implementation attributes significant |
| ENV | Leave-one-out     | TR                                          | 0.928 | <0.001  | All remaining implementation attributes significant |
| ENV | Leave-one-out     | OB                                          | 0.927 | <0.001  | All remaining implementation attributes significant |
| ENV | PCA /factor score | Component 1                                 | 0.934 | <0.001  | Exploratory DOI factor score                        |

an overarching implementation quality dimension. Exploratory DOI factor scores derived from the principal component were subsequently entered into regression analyses. The resulting models produced highly similar regression results (ED:  $\beta=0.958$ ,  $R^2=0.917$ ; SD:  $\beta=0.952$ ,  $R^2=0.907$ ; ENV:  $\beta=0.966$ ,  $R^2=0.934$ ; all  $p<.001$ ). Taken together, these robustness analyses indicate that the principal regression findings remain stable across alternative analytical approaches, while the PCA findings remain exploratory and should not be interpreted as formal validation of a higher-order implementation quality construct.

## 5 Discussion and implications

This study examined how policy implementation mechanisms derived from Rogers' Diffusion of Innovation (DOI) framework shape public sustainability evaluations conceptualised through the Triple Bottom Line (TBL) in the context of carbon pricing. Rather than focusing on innovation adoption decisions, the analysis interprets DOI constructs as features of policy design and implementation processes that shape perceived policy performance across Economic Feasibility (ED), Social Legitimacy (SD), and Environmental Credibility (ENV). The findings provide theoretical and practical insights relevant to sustainability governance and implementation effectiveness.

Across the three sustainability dimensions, the results reveal a consistent implementation-oriented evaluation pattern that remained stable across the robustness analyses

conducted in this study. Importantly, the strong covariance among DOI attributes suggests that respondents tend to evaluate implementation features in a highly integrated manner. One possible interpretation is that these implementation characteristics contribute to an overall perception of policy implementation quality, although this interpretation remains exploratory. Economic Feasibility (ED) and Social Legitimacy (SD) were positively associated with all five implementation mechanisms, indicating a consistent pattern of implementation-related associations across the two sustainability dimensions. This pattern suggests that individuals may assess affordability and fairness through expectations of how policies can be experienced, tested, and understood in practice. Environmental Credibility (ENV) was positively associated with all five implementation mechanisms, indicating a consistent association between implementation-related perceptions and environmental evaluation. This pattern suggests that perceived environmental credibility may be associated with observable outcomes and transparent reporting mechanisms. In addition, Perceived Policy Complexity (CX) remained significantly associated with all three TBL dimensions. Taken together, these findings indicate that the DOI implementation mechanisms remain conceptually distinguishable while exhibiting substantial empirical overlap. This pattern is consistent with the possibility that respondents form broader evaluations of implementation quality, although the present analyses do not establish a formal higher-order construct. These findings suggest that sustainability policy evaluations are shaped by a combination of experiential accessibility, procedural clarity, and outcome visibility, rather than by any single implementation attribute in isolation. This reinforces previous research emphasising the crucial role of demonstration effects and clarity in the diffusion of sustainability-related policies (Chen et al. 2021a; Liu et al. 2022).

Expected Policy Performance (RA) remained positively associated with all three sustainability dimensions. Given the substantial empirical overlap among the DOI implementation mechanisms, the findings are better interpreted as indicating an integrated pattern of implementation-related perceptions rather than clear differences in the substantive importance of individual mechanisms. This pattern suggests that respondents evaluated policy implementation through a highly integrated perception in which the implementation mechanisms were closely interconnected. In other words, perceived superiority is insufficient unless supported by observable and testable policy mechanisms. In particular, Social Legitimacy (SD) appears grounded in procedural clarity and implementation transparency instead of purely comparative efficiency claims. This includes clarity, fairness, and the extent to which policies can be meaningfully understood and experienced by affected groups (Zhang et

al. 2023a; Chen et al. 2021a). These findings refine DOI applications in sustainability governance by emphasising legitimacy-building implementation mechanisms alongside traditional innovation attributes.

From a theoretical perspective, this study contributes to the literature by integrating DOI with the TBL framework through an implementation-oriented lens. Whereas prior DOI studies have focused predominantly on technological uptake or behavioural adoption (Franceschinis et al. 2017; Münzel et al. 2020), the present results demonstrate that DOI attributes can be reinterpreted as dimensions of policy implementation quality that shape multidimensional sustainability evaluations. Beyond reinterpretation, the findings provide exploratory evidence that DOI attributes may be perceived in a highly integrated manner within environmental policy contexts, suggesting that respondents may form an integrated evaluation of policy implementation alongside their assessments of individual DOI attributes. These findings offer a possible refinement of DOI applications in environmental policy research by highlighting that implementation-related innovation attributes may be evaluated collectively in addition to individually. This perspective aligns with sustainability transition research, highlighting governance processes, institutional credibility, and implementation capacity as central determinants of policy acceptance and perceived effectiveness. At the same time, the exceptionally high explanatory power observed across the regression models should be interpreted with appropriate caution. Because both the DOI implementation attributes and the TBL evaluation dimensions capture closely related perceptions of carbon pricing, some degree of conceptual proximity between the implementation attributes and sustainability evaluation outcomes is expected. Accordingly, although the robustness analyses indicate that the findings remain stable across alternative model specifications, future research should further examine the distinctiveness of these constructs using confirmatory modelling approaches.

The findings have several implications for sustainability policy design and implementation. First, as an illustrative implementation consideration, policymakers may consider phased approaches such as localised regulatory sandboxes and sectoral piloting when operationalising Pilot-Based Implementation (TR). For example, policymakers may consider initially restricting carbon pricing to high-emission industrial clusters during an initial pilot period (e.g., 12–24 months). During this phase, governments can grant compliance grace periods or implement simulated carbon taxes without imposing immediate punitive financial penalties. Such an adaptive mechanism may help address concerns regarding Economic Feasibility (ED) and may support perceptions of Social Legitimacy (SD) (Chen et al. 2021a). Second, Outcome Transparency (OB) may be supported through

mechanisms such as digital MRV (Measurement, Reporting, and Verification) systems and transparent revenue-recycling frameworks. Environmental ministries should deploy public-facing digital dashboards that track real-time emission reductions alongside the exact distribution of carbon revenues. To foster trust in emerging economies, policymakers may consider legally earmarking a portion of these funds for clearly identified public purposes (Maestre-Andrés et al. 2021; Sommer et al. 2022). For example, a portion of carbon revenues could be allocated to electricity rebates for low-income households, while another portion could support an SME green modernisation fund. Such measures may also contribute to improving perceptions of distributive equity, an important consideration in the environmental justice literature on carbon pricing. Visibly linking tax collection to tangible social welfare may support perceptions of Environmental Credibility (ENV). Third, Perceived Policy Complexity (CX) may be addressed through measures that reduce compliance friction, such as tiered public communication and integrated compliance portals. Governments should simplify policy jargon by translating complex economic formulas into interactive tools, such as household carbon footprint calculators and automated SME tax estimators. Bureaucratic procedures for carbon accounting must be streamlined to fit within existing corporate tax reporting cycles. Reducing cognitive and administrative costs of compliance, particularly for smaller market players, may contribute to more favourable perceptions of policy feasibility and acceptance (Liu et al. 2025; Fesenfeld 2025), although the present study does not establish such effects causally or independently of the baseline pricing level. Collectively, these findings underscore that implementation design is as important as technical efficiency in determining policy success. The findings also have implications for decision-making under uncertainty because policymakers frequently implement carbon pricing without complete information regarding future public responses.

Although the empirical analysis is based on Malaysia, the findings provide implementation-oriented insights that may inform carbon pricing strategies in other emerging and developed economies implementing market-based climate instruments. Nevertheless, the strength and manifestation of these relationships may vary across national contexts because differences in governance quality, institutional trust, environmental awareness, and policy maturity can influence how stakeholders evaluate carbon pricing. In governance contexts characterised by evolving institutional trust and policy literacy, implementation transparency, experiential learning opportunities, and visible accountability mechanisms may be particularly relevant to how stakeholders evaluate carbon pricing policies. Consequently, implementation mechanisms such as regulatory sandboxes and transparent

revenue-recycling frameworks may provide a practical reference for emerging economies seeking to strengthen public acceptance and facilitate policy implementation.

For businesses and industry stakeholders, the findings indicate that communication surrounding carbon pricing should emphasise policy implementation mechanisms and demonstrable outcomes rather than abstract efficiency narratives. Specifically, where feasible, industrial associations and corporate leaders could be involved in the co-design phase of pilot sandboxes, allowing them to co-develop sector-specific operational case studies. Highlighting these tangible, localised co-benefits and implementation experiences within corporate sustainability reports can foster cross-industry collaboration and mitigate organised industrial resistance. Aligning corporate sustainability communication with implementation-oriented mechanisms, particularly Pilot-Based Implementation (TR), Outcome Transparency (OB), and Perceived Policy Complexity (CX) may facilitate collaboration and strengthen perceived policy legitimacy within industry ecosystems.

Lastly, the results highlight the need for future research to further examine sustainability policy acceptance through implementation-focused frameworks. Integrating behavioural and institutional constructs such as trust, procedural justice, and governance transparency may deepen understanding of how stakeholders interpret policy performance. Comparative and longitudinal studies across policy instruments and national contexts would also help assess whether these implementation-related associations remain stable over time. Overall, the findings suggest that DOI attributes can be interpreted as indicators of perceived policy implementation characteristics that are associated with multidimensional sustainability evaluations. The high interrelationships observed among the DOI attributes may reflect the way respondents form integrated evaluations of complex policy implementation processes. Because the present study was designed to examine the pattern of associations between theoretically derived implementation mechanisms and multidimensional sustainability evaluations, multiple regression was considered appropriate. Future studies should employ confirmatory SEM to examine whether the integrated implementation-quality interpretation suggested by the present exploratory findings can be empirically supported as a higher-order latent construct.

## 6 Conclusion

This study explored how policy implementation mechanisms derived from Diffusion of Innovation (DOI) theory are associated with public sustainability evaluations of carbon pricing by integrating DOI with the Triple Bottom Line

(TBL) framework. The results show that all five implementation mechanisms, namely Expected Policy Performance (RA), Socioeconomic Alignment (C), Perceived Policy Complexity (CX), Pilot-Based Implementation (TR), and Outcome Transparency (OB), were significantly associated with stakeholders' evaluations of Economic Feasibility (ED), Social Legitimacy (SD), and Environmental Credibility (ENV) of carbon pricing. Importantly, the findings indicate that all implementation mechanisms were significantly associated with the three sustainability evaluation dimensions while also exhibiting substantial interrelationships that may reflect an integrated perception of policy implementation quality.

All five implementation mechanisms were significantly associated with the three sustainability evaluation dimensions. Pilot-Based Implementation (TR) was significantly associated with Economic Feasibility (ED) and Social Legitimacy (SD), while Outcome Transparency (OB) was significantly associated with Environmental Credibility (ENV). Perceived Policy Complexity (CX), Expected Policy Performance (RA), and Socioeconomic Alignment (C) were also significantly associated with all three sustainability dimensions. Given the substantial empirical overlap among the implementation mechanisms, these findings should be interpreted as a consistent pattern of implementation-related associations rather than evidence that particular mechanisms are inherently more important than others. This pattern suggests that experiential and transparency-oriented implementation attributes may play a central role in shaping how stakeholders evaluate carbon pricing and may contribute to broader perceptions of implementation quality.

This study contributes to the DOI literature by demonstrating that innovation attributes can be interpreted within an environmental policy implementation context in addition to their traditional role in explaining innovation adoption. The observed interrelationships among the DOI attributes suggest that respondents may evaluate implementation characteristics in an integrated manner. Future research should examine whether this exploratory interpretation can be empirically supported using confirmatory factor analysis, structural equation modelling, or longitudinal research designs. The findings suggest that effective carbon pricing strategies should prioritise phased implementation, experiential learning opportunities, transparent performance monitoring, and clear administrative communication rather than relying solely on efficiency-based arguments.

Despite these contributions, several limitations should be acknowledged. First, the use of convenience sampling limits the statistical generalisability of the findings beyond the present sample. The large sample size does not eliminate the limitations associated with convenience sampling or the substantial empirical overlap among the study constructs.

The cross-sectional design restricts causal inference, and self-reported measures may introduce response bias. The exceptionally high explanatory power observed in the regression models should also be interpreted with appropriate caution, as both the DOI implementation attributes and the TBL evaluation dimensions capture closely related perceptions of carbon pricing. This conceptual proximity may partly contribute to the strong relationships observed among the variables. At the same time, robustness analyses, including leave-one-out regressions and exploratory factor-score analyses, indicate that the overall pattern of associations involving Pilot-Based Implementation (TR) and Outcome Transparency (OB) remained stable across alternative model specifications. Although several procedural remedies were implemented during questionnaire development and data collection to minimise the potential influence of common method bias, formal statistical assessments (e.g., Harman's single-factor test or marker-variable techniques) were not conducted. Future studies are encouraged to combine procedural and statistical approaches to provide a more comprehensive assessment of potential common method bias. Future studies using cross-country comparative or longitudinal designs would help evaluate the robustness and generalisability of these findings. Confirmatory factor analysis and structural equation modelling could further examine whether the exploratory integrated implementation-quality interpretation is supported as a higher-order latent construct across different institutional and policy contexts.

**Author contributions** All authors listed have made substantial contributions to the development and the writing of this article.

**Data availability** The data underlying this study will be provided upon request.

## Declarations

**Conflict of interest** The authors declare no competing interests.

**Ethical approval** This study involved an anonymous and voluntary survey of human participants. In accordance with institutional guidelines, formal ethics review was waived as no personally identifiable information or sensitive individual data was collected.

**Informed consent** Informed consent was obtained from all individual participants included in the study. As detailed in Section 3.2, the completion and submission of the voluntary, anonymous questionnaire was taken as informed consent to participate.

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