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PAPER

Patterns and gaps in co-benefit reporting in global adaptation research

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Abstract

Adaptations to extreme weather events are increasing in prevalence across the globe. Adaptation actions can produce co-benefits, which are ancillary positive outcomes beyond the primary objectives of reducing risk and enhancing resilience. Despite growing attention to co-benefits in the adaptation literature, systematic analyses across adaptation types, sectors, actors, and regions remain limited. This study uses the global adaptation mapping initiative database to investigate the associations between adaptation characteristics and the presence of co-benefits. We processed and coded 1684 articles, to categorize co-benefits and analyzed them alongside other adaptation characteristics through descriptive statistics, chi-squared tests, and logistic regressions. We found generally weak associations between adaptation characteristics and the presence of co-benefits. Further, the regression results showed that there were no significant differences between the associations with co-benefits of adaptations that occur across economic sectors. Ecosystem based responses were found to be more likely to be associated with the presence of co-benefits than human behavioral based responses. Technical or infrastructural responses were found to be less likely to be associated with co-benefits than human behavioral responses. Additionally, while some of the chi-squared associations and regression associations trended together, they also differed leading to ambiguity in the types of adaptations that often have co-benefits present. These findings highlight the need for improved co-benefit assessment frameworks and enhanced co-benefit documentation. Enhanced documentation could better inform adaptation planning and maximize the ancillary benefits of adaptation actions.

1. Introduction

Adaptation to extreme weather events focuses on adjusting systems to manage current and anticipated impacts, enhancing resilience and limiting risk. Adaptation strategies can yield co-benefits, which are ancillary positive outcomes that an action aimed at one objective might have on other objectives. There are a variety of co-benefit definitions found within the literature that include objective based, intent-based, and externality-based outcomes (Fung and Helgeson 2017). Across these types of co-benefits, scholars and practitioners have sought to understand when, why, and how co-benefits occur. Accounting for co-benefits typically offer enhanced economic efficiency to the outcomes of actions taken.

The assessment of health co-benefits from avoided emissions due to adaptation actions have long been an area of quantification and study (West *et al* 2013, Haines 2017, Karlsson *et al* 2020, Sharifi *et al* 2021, Kınay and Ji 2022). Growing attention is being directed toward the co-benefits of adaptation measures, such as urban infrastructure, including rain gardens and bioswale projects, and their co-benefits. For example, scholars have shown that various types of infrastructure also yield health-related co-benefits through improved air quality, enhanced thermal comfort, and increased opportunities for physical activity (Schmidt and Walz 2021, Sharifi *et al* 2021). In adaptation literature, urban adaptation behaviors and infrastructure have both been systematically studied with respect to co-benefits (Choi *et al* 2021, Sharifi *et al* 2021, Boyd *et al* 2022). Nature-based solutions in urban adaptation are most frequently associated with health-related co-benefits, while adaptations focused on urban buildings are more strongly linked to pollution reduction co-benefits (Sharifi *et al* 2021). Place-based research has also found adaptation co-benefits documented in sub-Saharan Africa (Suckall *et al* 2015), Bangladesh (Rahman *et al* 2022), Sri Lanka (Woroniecki 2019), and many other project or country-level assessments. Despite several large-scale reviews documenting the co-benefits of mitigation (Deng *et al* 2017, Karlsson *et al* 2020), sector specific reviews in the co-benefits of adaptation (Choi *et al* 2021, Sharifi *et al* 2021), and place-based studies, there remain gaps in systematic exploration of how different types of adaptation actions, spanning various sectors, actors, and regions, are linked to co-benefits. Additionally, the inconsistency in measurement of co-benefits makes comparisons across the literature difficult.

The uneven documentation of co-benefits across the adaptation literature could be due to a variety of reasons. Actions categorized as 'mitigation' and 'adaptation' can be used interchangeably in some contexts, but are considered distinct in most scientific literature (Watkiss *et al* 2015) and have a differing levels of understanding by the general public (Bruine de Bruin *et al* 2021). Additionally, systematic documentation of adaptation, itself, is a relatively new advancement (Berrang-Ford *et al* 2021b). Adaptation actions also fall upon a continuum of planned, autonomous (i.e. organic and self-organized), or mixed (Maskell *et al* 2025), thus have a broad range of actors and goals, making it difficult to quantify and generalize.

The lack of comprehensive documentation of co-benefits across adaptation types and sectors limits the ability of practitioners to design strategies that maximize co-benefits, potentially missing opportunities for integrated solutions that address both extreme weather and broader goals, as well as aid in economically efficient outcomes. Concerns about the costs of adaptation often hinder the adoption of adaptation at the local level; however, highlighting co-benefits can help address these barriers and encourage more effective solutions (Karlsson *et al* 2020). The resilience dividend, which is net co-benefits, accounting for co-costs, are important in building a business case for resilience (Fung and Helgeson 2017). Co-benefits can enhance a project's ability to manage uncertainty, proving especially valuable when hazard adaptation competes with other resource demands (Jones and Doberstein 2022). Recognizing and systematically documenting co-benefits is therefore essential for informing decision-making and measuring the benefits of adaptation strategies.

To advance the understanding of human adaptations to extreme weather events, the global adaptation mapping initiative (GAMI), a network of over 100 scientists and practitioners, conducted a comprehensive assessment of adaptation evidence (Berrang-Ford *et al* 2021b). This analysis provided summaries of adaptation evidence and its relation to natural hazards, stakeholders, geographic extent, and more (Berrang-Ford *et al* 2021b). Follow on analyses have also showed that adaptations targeting food security were more robustly documented (Torhan *et al* 2022) and adaptation documentation often identifies constraints to adaptation and rarely focuses on limits to adaptation (Thomas *et al* 2021).

This study aims to examine how adaptation actions across different hazards, sectors, actors, and locations are associated with co-benefits, providing a more holistic understanding of their distribution and informing more effective adaptation planning. We explore the associations between co-benefits of adaptation measures by utilizing the GAMI database. Two research questions guided this study: (1) how are adaptation actions that include co-benefits related or differentiated from those that do not? (2) What do significant correlations between adaptation characteristics and co-benefits reveal about potential challenges and opportunities? By addressing these questions, this study seeks to fill gaps in the literature, offering insights into how different adaptation strategies generate co-benefits and providing evidence to inform more integrated and effective adaptation planning.

2. Methods

2.1. Database and research questions

We utilized the GAMI database, developed through the collaborative efforts of adaptation experts to provide a comprehensive global assessment of adaptation actions (Berrang-Ford *et al* 2021b). The study systematically reviewed global academic literature from 2013–2019 to document how humans are adapting, applying PICoST and ROSES standards to guide search, screening, and reporting (Berrang-Ford *et al* 2021a, 2021b). Researchers used supervised machine learning and iterative human screening to efficiently identify studies that provided empirical evidence of real, documented adaptation actions aimed at reducing risk or vulnerability (Berrang-Ford *et al* 2021b). Ultimately, 1682 relevant articles were fully coded

Table 1. Overview of categories and variables included in the GAMI database.

Category	GAMI variables
Geography	Africa, Asia, Australasia, Central & South America, North America, Europe, Small Island states
Sectors	Food, cities, health, oceans, poverty, terrestrial, water, NA
Crosscutting topics	Polar regions, mountains, tropical forests, cities, biodiversity, Mediterranean, deserts, none, NA
Actors	International government, civil society international, civil society subnational, national government, subnational government, local government, private sector corps, private sector SMEs, individual communities, other, NA
Subgroups	Women, youth, elderly, low income, disability, migrants, indigenous, ethnic minority, other, none, NA
Response type	Technological/infrastructural, behavioral, ecosystem, institutional, NA
Hazard	Sea level, extreme precipitation, extreme heat, precipitation variability, drought, ocean temperature, Arctic Sea Ice, other, general climate change, no info, NA
Exposure	sustainable cities and communities, marine ecosystems, food, water, energy, poverty, health, education, gender equality, work economy, industrial innovation, consumer production, freshwater ecosystem, peace justice, no info, other, NA
Implementation stage	Vulnerability assessment, adaptation planning, implementation widespread, implementation expanding, risk reduction, NA
Cost	Cost of response, cost savings, none, NA
Other	Limits, indigenous knowledge, local knowledge, finance, reduced risk, indicators

by teams with regional and sectoral expertise, using a detailed codebook and quality-assured extraction process. Analyses classified adaptation actions by region, sector, hazard, actors, response types, and evidence of transformational change. The team then synthesized the findings using descriptive statistics, geographic text parsing, and an evaluation of adaptation depth, scope, speed, and limits (Berrang-Ford *et al* 2021b).

The database includes variables on geographic regions, sectors, actors, specific hazards, adaptation strategies, indigenous knowledge, financial costs, limits, and co-benefits (table 1). Details on the theory guiding the inclusion of these categories and variables was driven by the GAMI (Fischer *et al* 2021, Berrang-Ford *et al* 2021a, 2021b). For this study, we analyzed the co-benefits of this dataset. The co-benefits columns were initially recorded as open-text fields in the original GAMI database and subsequently coded into categorical and binary variables for the present analysis.

2.2. Co-benefit variable coding

The original co-benefit variable in the GAMI database was an open-text field, which required multiple processing steps to prepare it for categorical analysis (figure 1). We first examined the database to identify articles with missing co-benefit data. Of the 437 articles without an initial co-benefit response, three remained unclassified due to inaccessibility or translation issues. The remaining 434 articles were sent for manual coding, where two independent researchers reviewed and coded each article as *yes, no*, or *unsure*. In cases where coders disagreed ($n = 106$), the research team discussed them and either resolved conflicts to one answer or leveraged the code *mixed* to capture ambiguity, while consistent codes ($n = 328$) were retained as assigned. The distinction between manual and automated coding was based on the structure and reliability of the underlying data. Automated coding was applied only when co-benefit information appeared in short, keyword-based formats that could be classified consistently with rule-based parsing. Entries with missing data, longer open-text responses, or ambiguous wording required contextual judgment and were therefore manually dual-coded to ensure accuracy and consistency. This mixed approach allowed us to use automation where appropriate while maintaining data quality for variables requiring human interpretation.

Next, we processed the articles with existing co-benefit data in the GAMI database to determine if they contained easily identifiable binary response variables. For entries where co-benefits were clearly indicated using keywords ($n = 626$), we applied automated coding to classify responses as *yes, no*, or *mixed*. Keywords triggering a *yes* classification included 'yes,' 'stated,' 'mentioned,' and 'discussed,' while terms such as 'no,' 'none,' 'not,' and 'false' were used to classify entries as *no*. Entries that exceeded three words or contained ambiguous information ($n = 619$) were flagged for manual review. These articles were independently coded with the same process previously described including coding by at least two

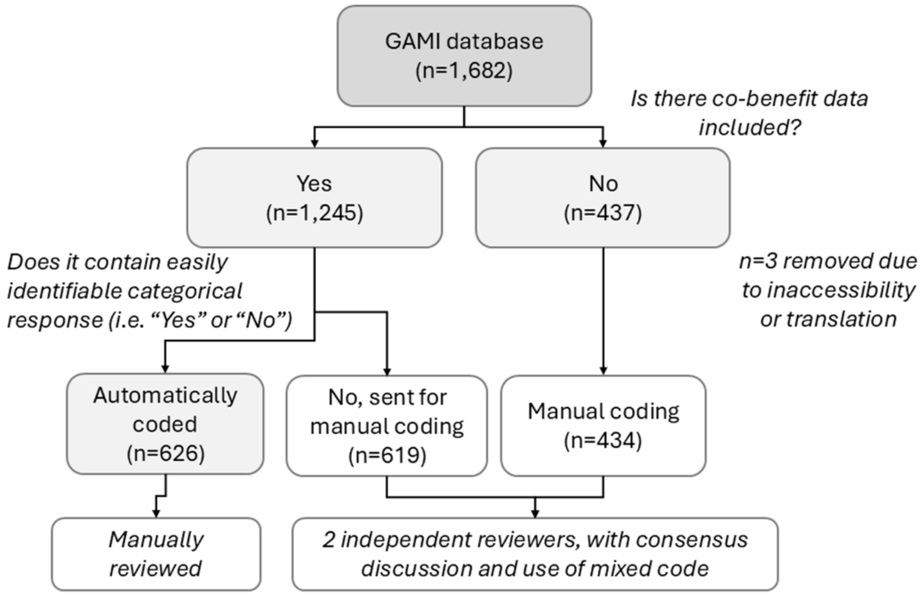

Figure 1. Methodological overview of coding process to turn GAMI data into categorical outcome variables.

researchers, with disagreements resolved through team discussion to reach consensus. Articles with conflicting reviewer codes—one indicating *yes* and another *no* that were not resolved in group discussion were categorized as *mixed*.

In total, 1053 articles underwent manual coding across both phases. The final distribution of the co-benefit variable was 39.1% ($n = 657$) coded as *yes*, 43.5% ($n = 731$) as *no*, and 17.3% ($n = 291$) as *mixed*. Three articles remained uncoded due to data accessibility constraints.

2.3. Statistical analyses

The multiselect categorical variables, or our adaptation characteristics (e.g. response type, geography, sector, hazard, subgroups, and indigenous knowledge, etc), in the GAMI dataset were converted into independent binary columns for each category, with a binary variable added to flag missing data. Each category within every variable was coded as a binary variable, indicating the presence (1) or absence (0). This process resulted in 96 binary variables, where 0 indicates the category was not mentioned in an article, and 1 indicates it was mentioned. A collinearity test showed most variables had a variance inflation factor (VIF) below 3.8, except for *indigenous* and *local knowledge*, which were highly collinear (VIFs of 94.43 and 94.25), reflecting significant overlap. Given the high collinearity between *indigenous* and *local knowledge*, we retained only *local knowledge* in the final dataset for analysis.

We conducted chi-square tests to assess associations between the co-benefit variable and all other categorical variables. To reduce the risk of type I errors, a Benjamini–Yekutieli correction was applied, adjusting the significance threshold to account for multiple comparisons (Benjamini and Yekutieli 2001). Cramer's V was used to measure the strength of these associations, with effect sizes categorized as weak (0–0.2), moderate (0.2–0.4), or strong (0.4–1.0), following established guidelines (Rea and Parker 2014).

We also developed a logistic regression model with co-benefits as the dependent variable and characteristics of the associated adaptation projects/interventions as independent variables. To examine their contributions, constructs were added incrementally, and correlation coefficients were compared across tests and models to ensure consistency. All analyses were performed using R statistical software.

To address mixed responses in the co-benefit variable, we conducted chi-squared tests to compare the 'Mixed' category with both 'Yes' and 'No' responses. The results indicated that the 'Mixed' category aligned more closely with the 'Yes' group, as there were fewer significant distinctions between 'Mixed' and 'Yes' compared to 'Mixed' and 'No.' This observation informed our decision to group 'Mixed' with 'Yes' as the preferred specification for our main analysis. The grouping of 'Mixed' with 'No' was retained as a robustness check and is included in the appendix for completeness. This approach reflects our effort to ensure that the classification aligns with the observed data while maintaining transparency in our methodological choices.

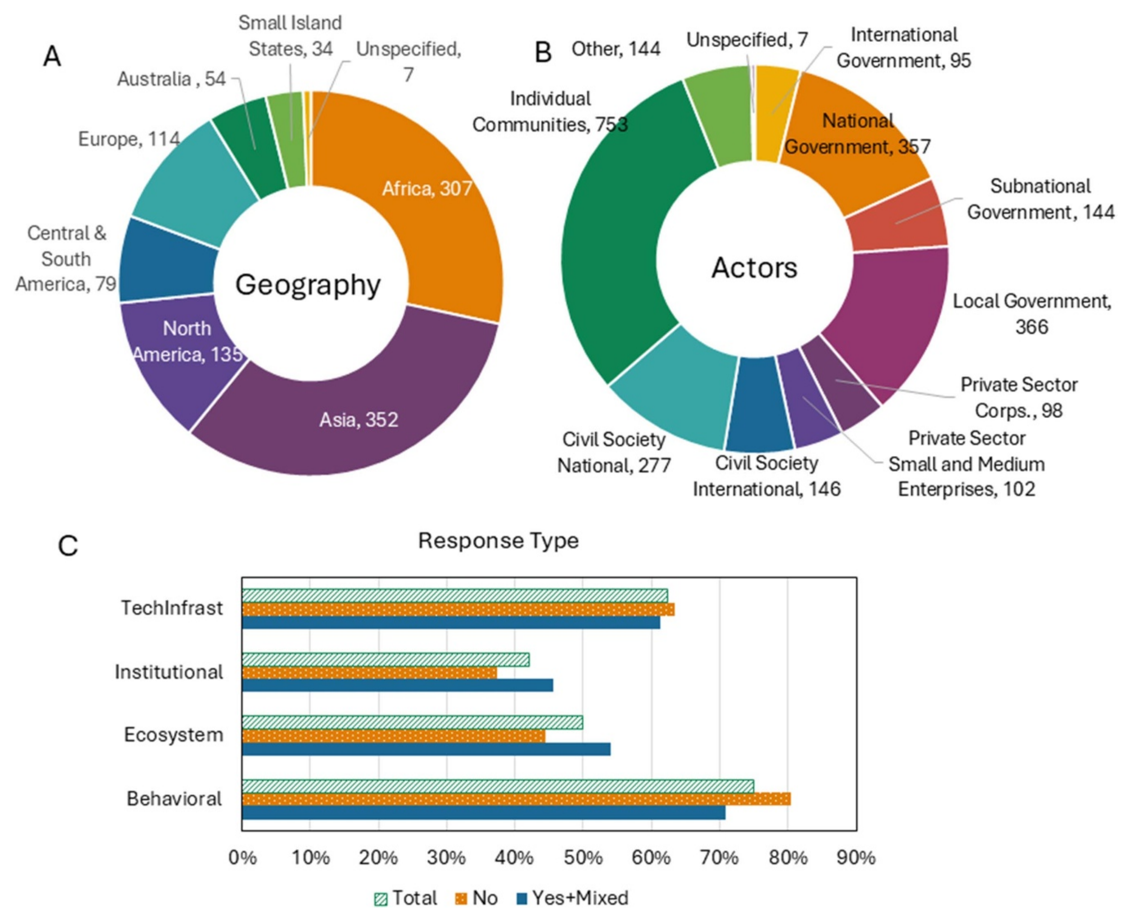

Figure 2. Geographic and thematic patterns in adaptation actions that include co-benefits. Panel (A). By Geography (count of articles), (B). By Actor (count of articles), (C). By Response Type (percent of articles). Panel (A) shows that co-benefit articles are most frequently documented in Asia and Africa. Panel (B) identifies the actors involved, with individuals and households playing the largest role, supported by civil society and sub-national governments. Panel (C) presents adaptation types, highlighting the prominence of behavioral/cultural, technological/infrastructural, and ecosystem-based responses. The denominator for each of the response types is either the total number of articles, for the total category, the total number of articles not including co-benefits for the no category, or the total number of articles that are yes and mixed responses for the yes and mixed category.

3. Results

3.1. How are adaptation actions that include documented co-benefits related or differentiated from adaptation actions that do not mention co-benefits?

Across our dataset, we found 948 articles with co-benefit mentioned (including the responses 'yes' and 'mixed') and 731 articles without. Adaptation actions reporting co-benefits were predominantly documented in Asia (37%) and Africa (32%) (figure 2(a)), aligning with the higher frequency of adaptation literature from these regions (Berrang-Ford *et al* 2021b, Torhan *et al* 2022). The participation of different actors in adaptation actions was examined, with individual and/or household actors identified in 753 co-benefit articles, or 79% of the articles (figure 2(b)). This indicates a strong presence of grassroots-level adaptations associated with co-benefits, reflecting the capacity of individual and community-driven initiatives to address local needs effectively while generating multiple positive outcomes. The involvement of civil society organizations and sub-national governments was also noted, suggesting a multi-level engagement in adaptation efforts that produce co-benefits.

Behavioral and cultural adaptation actions were associated with co-benefits, appearing in 71% of articles identifying co-benefits (figure 2(c)). Adaptations involving changes in behaviors, practices, and cultural norms are frequently linked to additional positive outcomes. Ecosystem-based adaptations were mentioned in 54% of co-benefit articles, while technological and infrastructural (TechInfrast) adaptations were noted in 61%. A total of 202 articles (12%) in the entire dataset addressed all identified adaptation types. The incorporation of local knowledge was relatively low in co-benefit articles, with only 17% of them mentioning local knowledge. Financial support was identified in 32% of co-benefit articles, while

Table 2. Overview of chi squared results of GAMI variables by category (comparing if co-benefits are related to each variable individually).

Category	Significant ($p < 0.05$)	Non-significant
Geography	—	Africa, Asia, Australasia, Central & South America, North America, Europe, Small Island states
Sectors	Cities	Food, health, oceans, poverty, terrestrial, water, NA
Crosscutting topics	—	Polar regions, mountains, tropical forests, cities, biodiversity, Mediterranean, deserts, none, NA
Actors	International Government, Civil Society International, Civil Society Subnational	National government, subnational government, local government, private sector corps, private sector smes, individual communities, other, NA
Subgroups	None	Women, youth, elderly, low income, disability, migrants, indigenous, ethnic minority, other, NA
Response type	Behavioral, Ecosystem, Institutional	Technological/infrastructural, NA
Hazard	General Climate Change	Sea level, extreme precipitation, extreme heat, precipitation variability, drought, ocean temperature, Arctic Sea Ice, other, no info, NA
Exposure	Sustainable Cities and Communities, Marine Ecosystems	Food, water, energy, poverty, health, education, gender equality, work economy, industrial innovation, consumer production, freshwater ecosystem, peace justice, no info, other, NA
Implementation stage	—	Vulnerability assessment, adaptation planning, implementation widespread, implementation expanding, risk reduction, NA
Cost	Cost Savings, None	Cost of response, NA
Other	Finance, Reduced risk, Indicators	Limits, indigenous knowledge, local knowledge.

the inclusion of indicators of success was noted in 40% of co-benefit articles. More descriptive details about the relationship between adaptation and co-benefits by geography, actors, and other variables can be found in the supplemental materials.

3.2. What do significant correlations between adaptation characteristics and co-benefits reveal about potential challenges and opportunities?

To explore the associations between various adaptation characteristics and the presence of co-benefits we conducted several analyses. Our chi-square tests identified significant correlations (tables 2 and 3), though the Cramer's V effect sizes, were generally weak, indicating modest associations. Additionally, we identified fewer significant associations than had been found in previous studies using the same database focused on other variables of interest (Torhan *et al* 2022). Among response types, behavioral adaptations exhibited the strongest relationship with co-benefits, followed by ecosystem-based and institutional responses. Risk reduction strategies and adaptations with clear indicators of success also showed strong associations, suggesting that measurable outcomes and a focus on mitigating risks are particularly relevant to co-benefit generation. Financial mechanisms and cost-saving strategies were additionally significant, highlighting the role of economic considerations in shaping co-benefit outcomes. International governance and civil society actors, particularly at both international and sub-national levels, were significantly associated with co-benefits, perhaps suggesting that the concept of co-benefits is being driven by civil society as opposed to national, subnational, or private sector actors. General climate hazards, sustainable cities, and marine ecosystems within the hazard and exposure categories also demonstrated significant, albeit weaker, associations, suggesting that these contexts may provide opportunities for co-benefit strategies. We did not find significant associations between co-benefits and adaptation actions aimed specifically at food security and health, despite these sectors being frequently mentioned in previous literature on co-benefits. This seems to indicate that, based on our data, adaptations in these sectors do not independently predict co-benefits. Given the size of the effect sizes and the number of significant associations, these results generally suggest that adaptation actions with the presence of co-benefits might not be markedly different than those that do not.

Building on the chi-squared analysis, logistic regression modeling was used to account for multiple variables simultaneously, allowing us to identify significant associations with co-benefits while controlling for potential interactions and confounding factors. The results from the logistic regression should be interpreted as comparisons between the reference category, which was omitted from the analysis and the category included in the regression. The value of the coefficient does not have a clear interpretation within this regression, but the direction and significance of the association can be interpreted from the

Table 3. Overview of Chi Squared Statistics for Significant Variables.

Category	Variable	X^2	P Value	Cramer's V
Sector	Cities	11.16	0.030**	0.083
Actor	Intl Gov	16.99	0.003***	0.103
Actor	Civ. Soc. Int	11.98	0.021**	0.086
Actor	Civ. Soc. Sub Nat	12.51	0.018**	0.088
Subgroups	None	12.14	0.021**	0.086
Response type	Behavioral	20.01	0.001***	0.111
Response type	Ecosystem	15.04	0.007***	0.096
Response type	Institutional	10.75	0.035**	0.081
Hazard	General climate	12.66	0.018**	0.088
Exposure	Sus Cities	10.38	0.040**	0.080
Exposure	Marine ecos	9.96	0.047**	0.079
Cost	Cost sav	12.86	0.018**	0.089
Cost	None	15.82	0.005***	0.098
Other	Finance	18.02	0.002***	0.105
Other	Reduce risk	42.97	0.000***	0.161
Other	Indicators	31.64	0.000***	0.138

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

results or the coefficients can be transformed into odds ratios or in other ways that allow for a more specific interpretation. A negative coefficient can be interpreted as being less associated with the presences of co-benefits than the reference category, while a positive coefficient can be interpreted as being more associated with the presence of co-benefits than the reference category. Additionally, we did create different models where variables were slowly added overtime to ensure consistency and robustness of the results. A summary of the full results section can be found in table 4 with detailed results found in the Supplemental Information table S2. Within the summary table the significant variables are differentiated by **positive in bold** and *negative in italics*.

The results for each geography found that there are no significant differences in presence of co-benefits, which is the same as the result from the chi squared analysis. For sectors, the regression results deviate from the chi squared results. The regression results showed that there were no significant differences between the associations with co-benefits of adaptations that happen cities as compared to other sectors. Within the crosscutting topics section there was also no significant associations with co-benefits. Adaptations with individual communities as the actor are less likely to be associated with co-benefits than adaptations with an international government organization as the actor. There are no significant associations in comparisons across different subgroups groups with the presence of co-benefits. Ecosystem responses are more likely to be associated with the presence of co-benefits than human behavioral responses. Technological/Infrastructural responses are less likely to be associated with co-benefits than human behavioral responses. There was no significant difference between behavioral and institutional responses with regard to the presence of co-benefits. Adaptations aimed at general climate change or without a specific hazard stated are associated with a higher presence of co-benefits than adaptations aimed specifically at sea level rise. Adaptations related to sustainable cities and communities are more commonly associated with the presence of co-benefits than adaptations aimed at food. There are no significant associations when comparing the stage of implementation of the adaptation action. Additionally, documenting reductions to risk and indicators of success are both positively associated with the presence of co-benefits.

4. Discussion

These results provide further insights into the associations between adaptation characteristics and co-benefits, revealing several significant associations while also highlighting broader patterns of uneven documentation.

4.1. Adaptation characteristics and co-benefits

Through descriptive statistics we document the locations of adaptations with co-benefits, both our chi-squared and regression results found that co-benefits were not linked to any region of the world. Similarly, for crosscutting sectors, implementation stage, and actors no significant associations were found in the chi squared analysis or the regression analysis. This differs from other analyses of this database that found several crosscutting sectors to be significantly associated with food, energy, and water

Table 4. Overview of logistic regression results by category.

Category	Reference Category	Significant GAMI variable ($p < 0.05$)	Non-significant GAMI variable
Geography	Africa	—	Asia, Australasia, Central & South America, North America, Europe, Small Island states
Sectors	Cities	—	Food, health, oceans, poverty, terrestrial, water, NA
Crosscutting topics	Biodiversity	—	Polar regions, mountains, tropical forests, cities, Mediterranean, deserts, none, NA
Actors	International government	*Individual communities (−)*	Civil society international, civil society subnational, national government, subnational government, local government, private sector corps, private sector SMEs, other, NA
Subgroups	Women	—	Youth, elderly, low income, disability, migrants, indigenous, ethnic minority, other, NA
Response type	Behavioral	**Ecosystem** (+), *Technological/ infrastructural (−)*	Institutional, NA
Hazard	Sea level	**General Climate Change, No info**	Extreme precipitation, extreme heat, precipitation variability, drought, ocean temperature, arctic sea ice, other, NA
Exposure	Food	**Sustainable Cities and Communities**	Marine ecosystems, water, energy, poverty, health, education, gender equality, work economy, industrial innovation, consumer production, freshwater ecosystem, peace justice, no info, other, NA
Implementation stage	Vulnerability assessment	—	Adaptation planning, implementation widespread, implementation expanding, risk reduction, NA
Cost	Cost of response	**Cost Savings, NA**	None
Other		**Reduced risk, Indicators**	Limits, indigenous knowledge, local knowledge, finance

adaptations in the GAMI database (Torhan *et al* 2022) and correlations of adaptation characteristics across several categories of actors (Araos *et al* 2021). Across both analyses, the cities sector was the only sector variable with association to co-benefits (chi-squared). Urban adaptation measures, particularly those involving nature-based solutions, have been extensively studied due to their visible health, social, and ecological co-benefits (Sharifi *et al* 2021), which may explain this sectoral significance.

Although not a direct result of our work, while drawing on existing theory, we can hypothesize over why there may be a limited number of significant associations between adaptations and co-benefits. As mentioned in our introduction, the concept of co-benefits itself is quite dispersed (Fung and Helgeson 2017) and in many ways sits at the center of adaptation decisions. This conceptual breadth can create inconsistencies in how co-benefits are defined, measured, and reported across studies, making it challenging to develop standardized methods for documentation. Existing co-benefit assessment methods are often case-specific, limiting comparability and replicability (Helgeson *et al* 2025). Developing standardized approaches, such as scoring systems or matrices, could improve consistency across studies (Helgeson *et al* 2025). Additionally, more systematic validation of these methods through monitoring and evaluation is needed to enhance their reliability in adaptation planning. Additionally, while mitigation and adaptation actions can overlap in practice, they are typically treated as distinct concepts in scientific research (Watkiss *et al* 2015), and public understanding of these terms often varies (Bruine de Bruin *et al* 2021). This disciplinary separation can lead to fragmented research approaches, where co-benefits are studied in isolation rather than through integrated frameworks, thereby limiting comprehensive analysis. When stakeholders and communities have differing interpretations of what constitutes a co-benefit, documentation may overlook or underreport outcomes that are not universally recognized.

4.2. Lack of documentation of co-benefits

The systematic tracking of adaptation efforts is a relatively recent development (Berrang-Ford *et al* 2021b). This emerging focus means that many adaptation projects may not have incorporated co-benefit assessments into their initial designs, leading to gaps in available data. Furthermore, early adaptation efforts may have prioritized immediate hazard responses over comprehensive evaluation of ancillary benefits, contributing to uneven documentation. Adaptation measures span a spectrum from planned interventions to autonomous or self-organized actions, with some falling in between (Maskell *et al* 2025). This heterogeneity in approaches, actors, and objectives complicates efforts to consistently measure and compare co-benefits. Planned adaptations, often supported by institutional structures and funding, may be more likely to include formal evaluations, whereas autonomous adaptations—driven by individuals or local communities—may lack the resources or technical capacity to document co-benefits systematically. This may be why we found in our results that individual actors were negatively associated with the presence of co-benefits. Additionally, the impact of confidence in one's own knowledge could impact co-benefit reporting in adaptation planning (Fischer and Fleming 2024). Additional research is needed to understand the exact mechanism that links individual actors and a decrease in co-benefit reporting.

Overall, our study results highlight both opportunities and challenges in understanding co-benefits across adaptation actions. The limited number of significant associations underscores the complexity of co-benefit realization and documentation, which is influenced by contextual factors, resource availability, and differing evaluation frameworks. Strengthening co-benefit assessment methodologies—through standardized metrics, improved data collection, and enhanced local engagement—could address current documentation gaps and support more comprehensive adaptation planning.

4.3. Limitations

This study has several limitations related to both the data source and the analytical methods employed. The GAMI database, while comprehensive in its review of peer-reviewed literature, excludes grey literature and unpublished reports, potentially omitting valuable insights from practice-based adaptation efforts (Berrang-Ford *et al* 2021b, Torhan *et al* 2022). Additionally, the database covers publications only up to 2019, which may not capture the most recent advancements or shifts in adaptation strategies. Several limitations around how the database was coded also exist. For example, the spatial resolution of the GAMI data is coarse, categorized at the continental level, which limits the ability to assess subnational or local variations in co-benefits. Furthermore, the adaptation variables and categories are based on a specific framework (Fischer *et al* 2021, Berrang-Ford *et al* 2021a), which may not align with other emerging classification systems or other ways to describe characteristics of adaptations. Additionally, researchers involved in coding the articles in GAMI did not always agree on if the adaptation documented considered co-benefits or if the article did not consider co-benefits. This lack of consistency could be due to different internal definitions of co-benefits or due to some researchers having different bars for discussion of co-benefits by the authors of the article to code the article as including co-benefits.

Methodologically, the exploratory nature of this study introduces its own set of limitations. Chi-square tests identify associations but cannot establish causality, and they may be sensitive to sample size and category distributions. Similarly, the regression models, while useful for identifying significant associations, are limited by the variables available in the GAMI dataset. These statistical approaches also assume linear relationships that may not fully capture the complexity of adaptation-co-benefit linkages. Future research could address these limitations by integrating more recent and diverse data sources, employing finer spatial resolution, and utilizing advanced modeling techniques to better understand the causal mechanisms behind co-benefit realization. While the GAMI data is the most? comprehensive evaluation of adaptations, the limitations of the data for use in analyzing co-benefits are a major limitation of this paper. Future adaptation research should measure co-benefits more directly and with more granularity.

5. Conclusions

This study highlights the complexity and variability in documenting co-benefits across adaptation actions. While certain adaptation characteristics, such as behavioral and ecosystem-based approaches, show stronger associations with co-benefits, the overall weak correlations suggest that co-benefit documentation is inconsistent and context-dependent. Factors such as limited resources, data availability, and long-term benefit realization timelines contribute to this variability. The regression analysis further illustrates that adaptations involving urban sectors are more likely to report co-benefits, while local-level and technology-driven adaptations remain under-documented. Improving co-benefit assessment requires standardized methodologies, robust monitoring frameworks, and stakeholder engagement to capture context-specific outcomes. Enhanced documentation of co-benefits can support more informed adaptation planning and maximize the return on investment in resilience-building measures.

The absence of comprehensive co-benefit documentation across adaptation types and sectors poses challenges for policymakers and practitioners, potentially limiting the design of strategies that fully capitalize on integrated solutions addressing both resilience and broader development priorities. Cost concerns often delay the implementation of adaptation and resilience building actions, but emphasizing co-benefits can help overcome these barriers and promote more economically efficient solutions (Karlsson *et al* 2020). The concept of the resilience dividend—which reflects net co-benefits after accounting for associated costs—plays a crucial role in justifying investments in resilience (Fung and Helgeson 2017). Co-benefits can also improve a project's ability to navigate uncertainty, especially when adaptation initiatives must compete with other pressing demands for limited resources (Jones and Doberstein 2022). Previous assessment of co-benefits have also shown that disaster adaptation investments change in a non-monotonic ways, which requires a constant long-term evaluation and show that consideration of multiple resilience dividends can enhance the attractiveness of adaptation efforts (Rözer *et al* 2023, Yokomatsu *et al* 2023). Thus, systematically identifying and reporting co-benefits is vital for informed decision-making and identifying cost-effective adaptation strategies.

Data availability statement

Restrictions apply. Data cannot be shared publicly via a URL/DOI. The data used is the data set from the GAMI analysis which has not been publicly released by the authors.

SI Gore et al. ERC 2026 available at https://10.1088/2752-5295/ae390a/data1.

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