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Opportunity for health and wellbeing co-benefits of climate adaptation policies and programs: a Delphi study in the Australian Capital Territory

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Abstract

The integration of health and wellbeing co-benefits into climate policy and decision-making is limited. This study aimed to identify health and wellbeing co-benefits of climate change adaptation and mitigation, assess the perceived relevance and importance of co-benefits to policy and programme evaluation, and assess data availability to measure co-benefits. The relevance, importance, and data availability of 24 co-benefits of climate policies and programmes identified from a prior scoping review were surveyed using Delphi methodology by experts across diverse policy areas using the Australian Capital Territory (ACT) as a case study. We created an opportunity score that represented the combined relevance and importance for each co-benefit. Experts also identified additional co-benefits and provided qualitative responses, with agreement with the first round results assessed in the second round. We found that co-benefits that were rated as highly relevant were generally rated as highly important. The top five co-benefits based on opportunity score (relevance × importance) included: reduced mental health burden; increased comfort in the home; improved disaster preparedness; improvement in physical health; and economic benefits from averted healthcare costs. A high degree of consensus was achieved for all five top co-benefits, as well as those considered not relevant or important, indicating agreement on highest and lowest priority co-benefits across a range of climate change interventions and government directorates. While most co-benefits with high opportunity scores had available data, the availability of quality data was a key concern, with over half the identified co-benefits having no available data or uncertain data availability. Future research needs to develop a standardised methodology to measure co-benefits that incorporates indicators considered most relevant and important by experts, with the prioritisation of co-benefits in this Delphi study providing a guide for research and evaluation in other contexts beyond the ACT.

1. Introduction

Climate change is a significant and urgent global issue that is adversely affecting human and planetary systems (IPCC 2023). In urban areas, climate change has negatively impacted human health, livelihoods and key infrastructure including transportation, water, sanitation, and energy systems (IPCC 2023, Romanello *et al* 2022). A policy response that integrates health into its mitigation and adaptation targets may not only minimise serious adverse health effects but also improve health outcomes as co-benefits of policies and programmes (Romanello *et al* 2023). These health and wellbeing co-benefits are defined as the unintended

or additional benefits of policies or programes and can range from reduced morbidity and mortality to social and economic benefits, that can result in significant and positive impacts beyond the intended goals of climate action (Jennings *et al* 2020, Sharifi *et al* 2021, Fernandez-Guzman *et al* 2023). Such co-benefits offer significant incentives for key stakeholders to support climate action, as well as offering improved prioritization of resources and the ability to efficiently address complex social, environmental, and economic challenges (Scovronik *et al* 2019, CDP 2020, Karlsson *et al* 2020).

Despite the value of co-benefits, they are often not adequately considered in policy decision-making and their inclusion is bounded by limitations in existing research and data reporting (Karlsson *et al* 2020). Almost a quarter of the 861 cities that voluntarily report on climate and environmental performance data to the global CDP-ICLEI Unified Reporting System do not report on co-benefits associated with climate action and amongst those that do, the range of co-benefits that are reported is limited (CDP 2020). This is also reflected in the limited breadth and depth of existing literature, as many co-benefits are under-researched (Karlsson *et al* 2020, Tham *et al* 2020). More specifically, recent literature reviews identified a limited variety of indicators for co-benefits of climate change policies and programmes, with a strong focus on mortality outcomes and inadequate consideration of broader wellbeing measures that relate to quality of life (Karlsson *et al* 2020, Fernandez-Guzman *et al* 2023). Our own scoping review also found limited integration of indicators for a variety of health and wellbeing co-benefits, especially in the evaluation of implemented policies and programmes (Becvarik *et al* 2024). This highlights the need for further identification of a comprehensive set of health and wellbeing co-benefits using methodology that maximizes the utility of such research for application in policy or programme implementation and evaluation.

To address this research gap, we conducted a Delphi study that aimed to: (1) identify health and wellbeing co-benefits of climate change adaptation and mitigation; (2) assess their perceived relevance and importance to policy and programme evaluation; and (3) identify associated data availability for measuring co-benefits. A Delphi method involving two online survey rounds was selected as it is an iterative methodology that enables insights into research phenomena, as well as consensus building (Okoli and Pawlowski 2004). This research methodology enables empirical validation of existing research on co-benefits and understanding of co-benefits for which there is limited research in the literature. This has policy and research utility for both the Australian Capital Territory (ACT) where the Delphi was conducted, as well as wider relevance for government policy and practice in Australia and globally.

2. Methods

As seen in the workflow below (figure 1), this study utilizes a case study in the ACT to investigate the relevance, importance, and data availability of health and wellbeing co-benefits in the 'real-world' policy context of policymakers and government officials who are subject matter experts based on applied professional engagement and practice.

2.1. Initial steps in identifying health and wellbeing co-benefits

Prior to the Delphi study, a scoping review was conducted to identify and assess literature that examines the health and wellbeing co-benefits of climate action in urban areas and to identify co-benefits that could be incorporated into policy and program evaluation (Becvarik *et al* 2024). This scoping review informed the co-benefits presented to experts in the Delphi study.

As part of a collaboration with the Environment, Planning and Sustainable Development Directorate (EPSDD) in the ACT Government, the research team conducted a workshop on the 25 October 2023. The purpose of this workshop was two-fold. Firstly, it was designed to cultivate interest and engagement in the project by other ACT Government Directorates and subject matter experts working in policy areas relevant to the study. These individuals would later be invited to participate in the Delphi study, and some would form part of a reference group providing expertise throughout the project. Secondly, the workshop was intended to inform the design of the Delphi survey and flag any additional co-benefits or data access issues that should be addressed in the Delphi study, as well as inform the language and content of the surveys. This workshop was discussion based, with participants discussing key questions, such as what co-benefits they identified in their field of work, with the research team flagging any co-benefits that had not been identified through the literature review for inclusion in the Delphi. Through the workshop, it was ascertained that the Delphi needed to include the following considerations to be most useful for policymakers: the likelihood that a co-benefit would result from a programme or policy, its importance in evaluating that intervention, and whether there is available data to assess it. As these discussions directly informed the Delphi, we did not publish the workshop outputs independently.

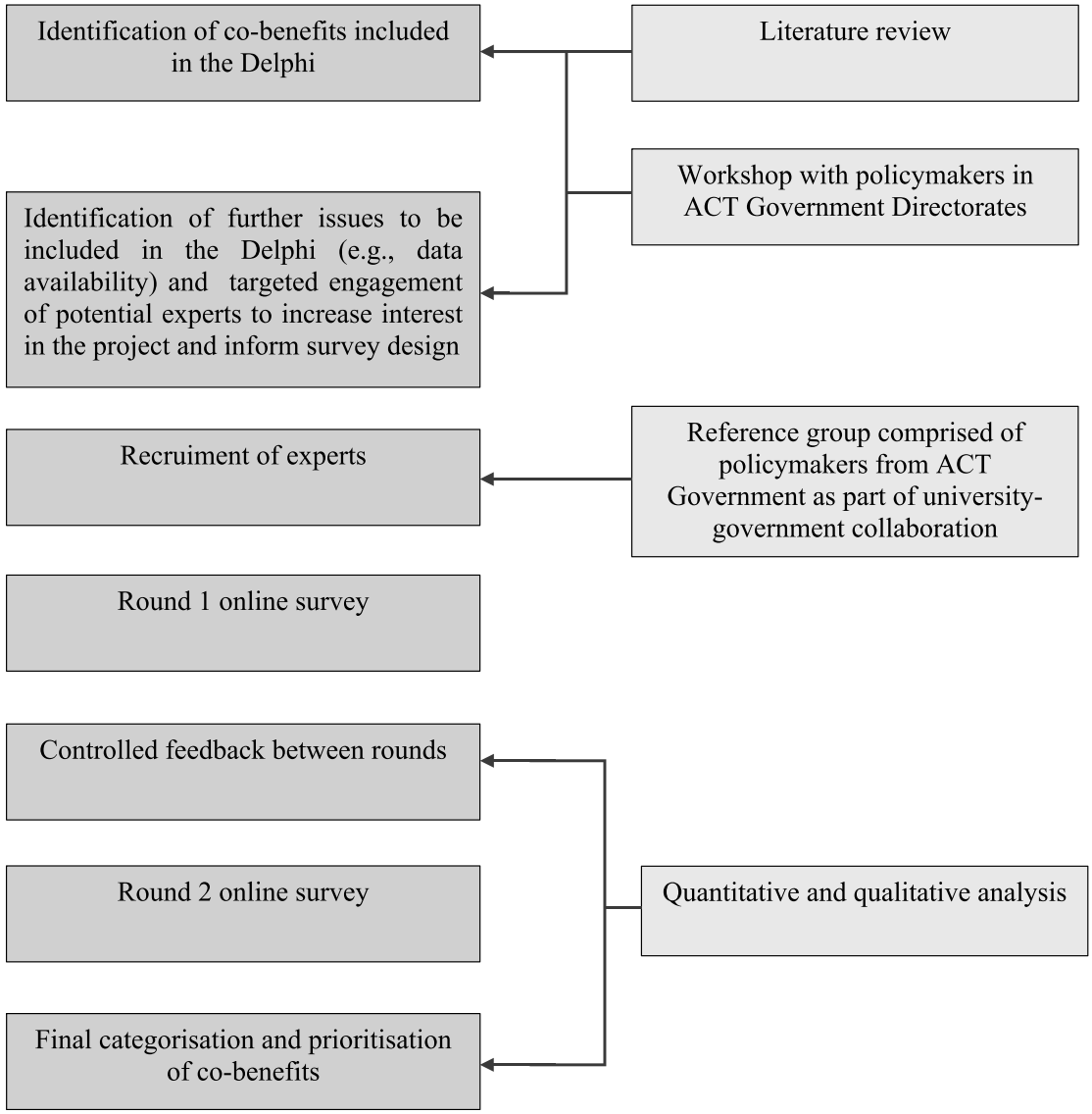

Figure 1. Workflow of Delphi study with ACT Government policy experts.

2.2. Recruitment and eligibility

Eligibility criteria stipulated that participants had to be over 18 years of age, as well as subject matter experts in the design and/or implementation of ACT government policy in the areas of: climate, household energy, wellbeing measures, health, housing community services and education. The Delphi method differs from traditional survey methods as the group size does not depend on statistical power but instead on group dynamics necessary for achieving consensus, with the literature recommending between 10–30 experts for consensus building (Rayens and Hahn 2000, Okoli and Pawlowski 2004). This study therefore aimed to recruit 10–30 participants representing a range of ACT Government Directorates.

Participants were recruited by the ANU research team through targeted participant invitations. Email invitations were sent to individuals who expressed interest in the co-benefits research project, such as through workshop attendance, and individuals identified through the EPSDD team's existing networks across ACT Government Directorates.

The email invitations provided potential participants with general information about the project and research purposes and directed them to the survey via a link to Qualtrics (an online survey platform with in-built functionality for quality review and analysis) (Qualtrics 2025). More specific details about the research project were provided in the participant information sheet once the participant clicked on the link.

2.3. Round 1 of the Delphi study

The first round of the Delphi study was conducted as an online survey between 9th February and 14th of March 2024, with participation being voluntary and unpaid. The ethical aspects of this project were approved by the Australian National University Human Ethics committee (Protocol H/2023/1275).

2.3.1. Survey content

Participants were presented with a list of 24 health and wellbeing co-benefits and asked a series of questions related to the relevance, importance and data availability of co-benefits, whilst thinking about climate change adaptation policies and programmes that relate to their specific area of expertise (see appendix 1). Participants were also able to add to this list and provide free-text responses for all aspects of the survey. The survey content was directly informed by the literature review and pre-liminary workshop, as well as discussions with government stakeholders regarding what knowledge of co-benefits would be most useful from a policy perspective. As outlined in appendix 1, relevance scores reflected the likelihood that a statement in the survey was a co-benefit of a climate change adaptation programme and/or policy; importance scores reflected the perceived importance of the co-benefit to measuring the overall success of a climate change adaptation programme and/or policy; and data availability scores reflected whether there was existing data that could be used to measure the co-benefit. Pre-testing was conducted with several government stakeholders who met the inclusion criteria.

2.3.2. Quantitative and qualitative analysis

The data was analyzed using Qualtrics and Microsoft Excel. The mean, median, IQR and standard deviation for each set of responses (relevance, importance and data availability) were calculated in addition to opportunity scores for each co-benefit which were used to rank them. The opportunity score represented the combination of relevance (i.e. whether the co-benefit was likely to result from a given climate change adaptation programme and/or policy) and importance (i.e. whether the co-benefit was important in evaluating policy or programme success). As relevance and importance were ranked independently on a 5-point likert scale from not important or relevant at all (1) to very important or relevant (5) (see appendix 1), the maximum opportunity score was 25 (i.e. 5×5).

Co-benefits were also ranked based on their mean data availability score. Participants were asked whether the co-benefit could be measured with existing data, with scores rounded to the nearest 0.5 to delineate three categories (no available data—0, not sure—0.5, and data available—1). Cut-offs for rounding the data into three categories were developed by creating groups of equal size based on the different values for data availability. Results for data availability were also analyzed in relation to opportunity scores together to capture how data availability may relate to perceived relevance and importance of co-benefits by subject matter experts in the ACT Government. The preliminary workshop also provided contextual understanding of the nuances of data availability and who operated as data custodians.

A key feature of Delphi surveys is the determination of consensus amongst experts. There are a number of features that can be used to quantify consensus, including the interquartile range (IQR) which is the absolute value of the difference between the 75th and 25th percentiles (Rayens and Hahn 2000, Birko *et al* 2015). Whilst this is a common method, there is limited agreement on the interpretation of IQRs as a measure of consensus (Rayens and Hahn 2000, Nasa *et al* 2021). In general, smaller values indicate higher degrees of consensus, with an IQR of 1 or less typically used to indicate strong consensus for 4 or 5 unit response scales (Persai *et al* 2016, Ratwatte *et al* 2023). Where an IQR value$\leqslant$1, it indicates that over 50% of all responses lie within a single point on the response scale. In the case of this study, strong consensus was defined where IQR values were one or less, and more dispersed responses were indicated by IQR $>$1.

Content analysis of the free-text qualitative data was conducted by categorizing responses into themes, identifying additional co-benefits from open-ended responses, and other data driven qualitative approaches. Selection of statements for inclusion in this article were based on the principles of authenticity, specificity, and representativeness of the themes identified, as well as selecting quotes from different experts and the consistency between the data presented and the rest of the study findings (Tong *et al* 2007, Cristancho *et al* 2021).

2.4. Round 2 of the Delphi study

The second round of the Delphi study aimed to assess the level of agreement with Round 1 results, as well as the perceived relevance, importance, and data availability of additional co-benefits identified by experts in the first survey round. The second round of the Delphi study was conducted from the 18 May 2024 to the 18th of June 2024 online using the Qualtrics survey platform.

The emails of participants who completed the first round were used to re-contact participants for the second Round. Eligibility for participation in the second round was the same as the first round, except participants also had to have completed Round 1.

2.4.1. Survey content

Experts were provided with controlled opinion feedback from Round 1 through the presentation of a short summary of Round 1 results, including general demographic information on participants and trends in opportunity scores (Meijering and Tobi 2016).

The same list of 24 co-benefits used in the first survey round, along with the average response for how relevant and important experts had rated each co-benefit, as well as average scores for data availability, were presented to experts (appendix 2). Experts were asked to assert their agreement with the average scores on a two-point scale (agree or disagree). For the additional co-benefits identified by experts in the first survey round, experts were asked to rate them according to their relevance, importance and data availability, as in the first survey. Experts were also able to provide open-text responses regarding the data availability of the additional co-benefits, as well as the overall results from the first survey.

2.4.2. Quantitative and qualitative analysis

Level of agreement with the relevance, importance and data availability ratings from Round 1 were analyzed through calculation of mean, median, IQR and standard deviation. Consensus in Round 2 was assessed based on the level of agreement with the Round 1 results. There is no standard agreed for cut-off thresholds for consensus in the literature, with consensus cut-offs selected arbitrarily and ranging from percentage agreement of 50%–97% (Nasa *et al* 2021). However, a cut-off of 75% has been commonly used in the literature to indicate a high level of support and consensus for survey components (Barrios *et al* 2021, Austinavicius *et al* 2022, Alford *et al* 2023). Based on the literature, we determined *a priori* that percentage agreement of 75% or more indicates a high level of consensus (i.e. strong consensus), but that percentage agreement of 50% or more still indicates a degree of consensus. Co-benefits were ranked based on the level of agreement, with analysis comparing level of agreement with opportunity scores and data availability.

The additional co-benefits identified in Round 1 were analyzed and re-categorized into four co-benefits for inclusion in Round 2, based on similarity to the existing list of 24 co-benefits and whether they could be understood as discrete and measurable co-benefits. The mean, median, IQR and standard deviation for each set of responses (relevance, importance and data availability), as well as opportunity scores, were calculated for the additional co-benefits. When rounding the data availability scores of additional co-benefits in order to assign them to one of the three categories of data availability (available data, uncertain data availability, and unavailable data), we used the same cut-offs from Round 1. The additional co-benefits were ranked with all other co-benefits based on their mean opportunity score. Pearson correlation coefficients were also calculated.

3. Results

3.1. Round 1

A total of 19 experts completed the Delphi survey. All experts agreed that they were subject matter experts in climate, energy, health and wellbeing, housing, transport, community services or education (or adjacent areas) with regard to policy/programme development or implementation. Approximately 82% of experts were assistant directors, directors or senior directors; remaining experts filled positions such as branch manager, public health physician and chief executive officer. Experts therefore represented a core workforce at the executive level. Experts represented seven ACT Government Directorates including: Environment, Planning and Sustainable Development; ACT Health; Canberra Health Services; Chief Minister, Treasury and Economic Development; Community Services; Transport and City Services; and Education.

Results from ranking co-benefits based on opportunity scores (relevance x importance) showed that experts perceived the co-benefits presented as having varied relevance and importance to the evaluation of climate change adaptation and mitigation polices and/or programmes. Opportunity scores for co-benefits ranged from 6.59 to 14.93. The top five co-benefits based on opportunity score were reduced mental health burden (14.93), increased comfort in the home (14.90), improved disaster preparedness (14.10), improvement in physical health (14.09), and economic benefit due to averted healthcare costs (13.34). The bottom 5 co-benefits based on opportunity scores included reduced community noise and/or disturbance (7.20), reduced aggression and violence (7.02), reduced exposure to food and water-borne diseases and other

contamination exposures (6.73), reduced incidence of adverse birth outcomes (6.72), and reduced incidence and/or burden of injury (6.59). Co-benefits that were rated as having a higher relevance were generally rated as having higher importance (Pearson correlation coefficient $= 0.82, p < 0.01$).

Whilst co-benefits had differential relevance and importance, descriptive statistics for mean relevance and importance indicated that there was not a large spread in how experts rated co-benefits. For example, in the case of the mean relevance of reduced mental health burden being a co-benefit in policies and programmes, the IQR was 1 and the standard deviation was 0.98. In the case of relevance, consensus was reached for the majority of co-benefits, with 70% of all co-benefits having an IQR for the relevance score of 1 or less and all other co-benefits having an IQR for the relevance score between 1 and 2. Consensus was not as strong for the importance of co-benefits; 50% of co-benefits had an IQR for importance scores of 1 or less and almost all others had an IQR in the range of 1–2.

Perceived data availability also varied according to the co-benefits considered. Following rounding of mean data availability scores, two-thirds of co-benefits were believed by experts to have no relevant available data or experts were unsure about data availability. Experts therefore only perceived a third of the listed co-benefits as having available data that could be used in evaluation. Consensus on data availability was strong, with all co-benefits having an IQR for availability of 1 or less and the average IQR for availability across all co-benefits was 0.48.

3.2. Round 2

A total of 10 experts completed the Round 2 Survey out of a total 16 experts who provided their contact information for follow-up at the end of Round 1. This reflects a 52.6% response rate, and 47.4% attrition rate between Round 1 and Round 2. The primary focus of work for experts who completed Round 2 included: energy efficiency and home upgrades for vulnerable households (3 experts), health (4 experts), material and energy poverty reduction (1 expert), economic modeling (1 expert), and climate change policy (1 expert). This reflects a diverse range of expertise and aligns with many of the Directorates identified in Round 1, other than education and transport.

Agreement with the mean scores from Round 1 varied according to relevance, importance and data availability, as well as the co-benefits assessed. For relevance and importance scores, agreement was high for co-benefits that were rated as relevant and important, as well as the co-benefits that were rated as not relevant and not important. More specifically, all co-benefits that were rated as relevant and important in Round 1 had an 80%–100% agreement rate, indicating a high-level consensus based on our pre-defined thresholds. Figure 2 shows that for all top five co-benefits based on opportunity score (relevance $\times$ importance), agreement was very high and there was 100% agreement on the importance of all top five co-benefits. Furthermore, co-benefits that were rated as not relevant or not important had agreement rates of 90%, indicating a high level of consensus. However, a wider range of agreement and therefore consensus was seen for neutral relevance and importance scores.

Whilst all co-benefits had agreement ratings of over 50% for data availability scores, and therefore indicated a degree of consensus, there was not a clear trend between the level of agreement and data availability status. Co-benefits with high agreement scores (i.e. over 80%) included mostly those with uncertain data availability, but also available data and no available data. The only co-benefit with 100% agreement for data availability was reduced aggression and violence, which was determined not to have available data.

The four additional co-benefits identified in Round 1 and included in Round 2 were rated by experts as having differential relevance, importance, and data availability. The ratings for these additional four co-benefits were incorporated into the ranked list of co-benefits from Round 1. Figures 3 and 4 present the ranked list of all 28 identified co-benefits. Calculation of a Pearson correlation co-efficient indicated a statistically significant positive association between relevance and importance of co-benefits, as well as statistically significant positive relationships between data availability and both relevance and importance.

According to the categorization system seen in table 1, five co-benefits were of high importance and high relevance and all of these co-benefits also had data available. No co-benefits were categorized as being of high importance and low relevance or low importance and low relevance. Nine co-benefits were of either high relevance and low importance or had a small difference between relevance and importance. Data availability

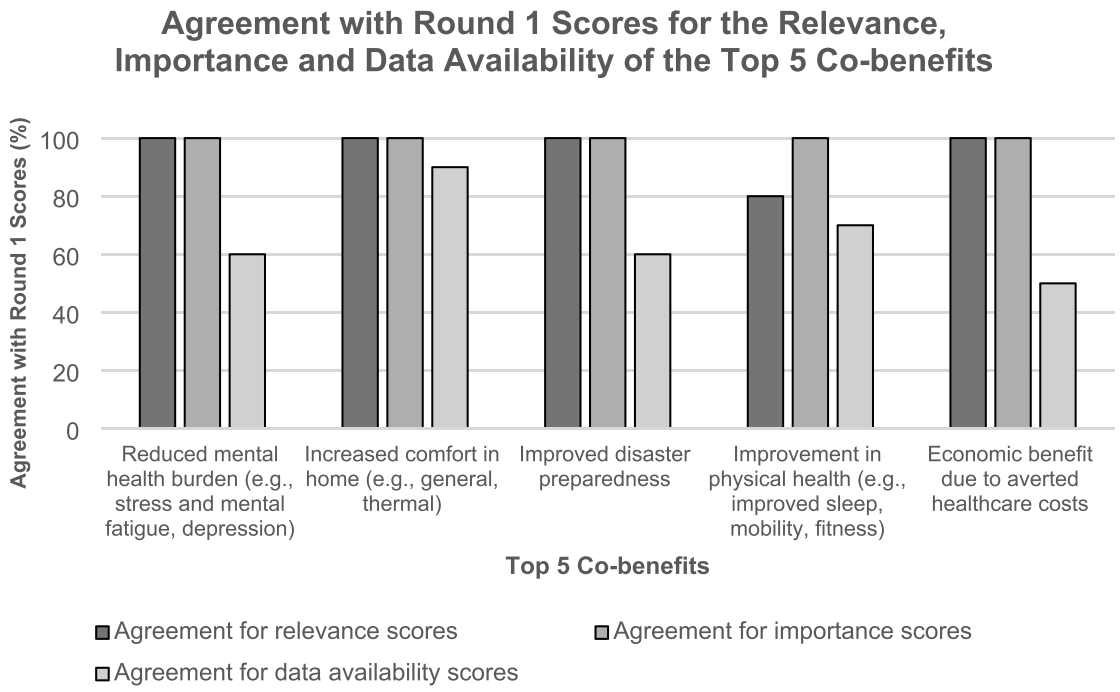

Figure 2. Agreement with Round 1 scores for relevance, importance and data availability of the top five co-benefits.

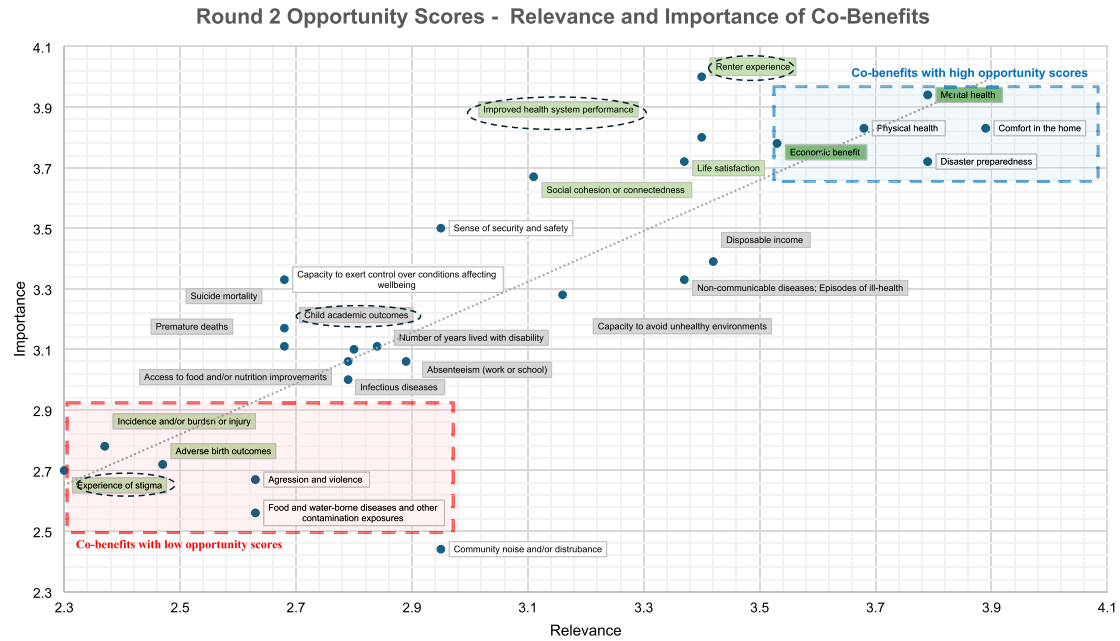

Figure 3. Opportunity score—relevance and importance of co-benefits. Figure depicts a scatterplot with average scores for relevance (*x*-axis) and importance (*y*-axis), with the inclusion of the scores for additional co-benefits from Round 2 (circled in black). Co-benefits are shown by a shortened label (see key). The top five (blue) and bottom five (red) co-benefits based on opportunity score are highlighted.The following color codes were used based on the categories of opportunity scores presented in table 1: Dark green represents high opportunity co-benefits; grey represents neutral co-benefits; and light green represents co-benefits with a small difference between likelihood and importance or where likelihood is high but importance is low. The Pearson correlation co-efficient for relevance and importance is 0.79 ($p < 0.01$). Note both axes reflect the range of data, and do not extend to 0.

Key: description of co-benefit labels.

Label	Description of Co-benefit
Disposable income	Increased disposable income for program participants
Community noise and/or disturbance	Reduced community noise and/or disturbance
Comfort in the home	Increased comfort in home (e.g. general, thermal)
Episodes of ill-health	Reduced episodes of ill-health (e.g. in number of doctor or emergency room visits)
Adverse birth outcomes	Reduced incidence of adverse birth outcomes (e.g. pre-term birth and low birth weight)
Access to food and/or nutrition improvement	Improved access to food and/or other related nutrition improvements
Absenteeism (work or school)	Reduced number of days off work or school (i.e. reduced absenteeism)
Incidence and/or burden of injury	Reduced incidence and/or burden or injury
Mental health	Reduced mental health burden (e.g. stress and mental fatigue, depression)
Sense of security and safety	Improved sense of security and safety
Food and water-borne diseases and other contamination exposures	Reduced exposure to food and water-borne diseases and other contamination exposures
Physical health	Improvement in physical health (e.g. improved sleep, mobility, fitness)
Life satisfaction	Improved life satisfaction
Disaster preparedness	Improved disaster preparedness
Premature death	Reduced incidence of premature deaths
Non-communicable disease	Reduced impact from non-communicable diseases on household members (e.g., cardiac diseases, diabetes, respiratory disease)
Capacity to exert control over conditions affecting wellbeing	Improved capacity for individuals to exert control over conditions that affect their wellbeing (e.g. stopping smoking, buy nutritious foods)
Social cohesion or connectedness	Improved social cohesion or connectedness (e.g. increased time spent with other people)
Number of years living with disability	Reduced number of years lived with disability
Infectious diseases	Reduced incidence of infectious diseases on household members (e.g. legionnaires disease)
Capacity to avoid unhealth environments	Improved capacity to avoid unhealthy environments
Aggression and violence	Reduced aggression and violence (neighborhood and/or domestic)
Economic benefit	Economic benefit due to averted healthcare costs
Suicide mortality	Reduced suicide mortality
Renter experience	Improved renter experience (e.g. increasing purchasing power, reduced rent-related stress)
Improved health system performance	Improved health system performance
Child academic performance	Improved academic outcomes in children
Experience of stigma	Reduced experience of stigma (e.g. due to improved home environment)

for these co-benefits was mixed, with five out of the nine co-benefits in this category being associated with available data. The majority of co-benefits were categorized as having neutral relevance and importance, and these co-benefits had generally poorer or more ambiguous data availability overall.

4. Qualitative analysis

Analysis of open-ended text responses from both survey rounds revealed rich qualitative insights into what experts thought additional co-benefits could be and how they thought about co-benefits overall.

In general, experts perceived co-benefits to have a significant and highly positive impact on people's lives and in the evaluation of policies and programmes. For example, one expert talked about an energy efficiency programme that provided thermally backed curtains to low-income/vulnerable houses. They stated that such programmes offered important co-benefits as they:

'*…help improve thermal comfort of the households but they also provide much needed privacy and a greater sense of security to vulnerable households*'.

Table 1. Cross tabulation of opportunity categorization and data availability.

	Data Availability			
Opportunity	No	Not Sure	Yes	Total
High importance/High likelihood	0	0	**5**	**5**
Low importance/low likelihood	0	0	0	0
High importance/low likelihood	0	0	0	0
There is a small difference between likelihood and importance; or likelihood is high but importance is low	**1**	**3**	**5**	**9**
Likelihood and importance are both ranked as neutral	**6**	**6**	**2**	**14**
Total	**7**	**9**	**12**	**28**

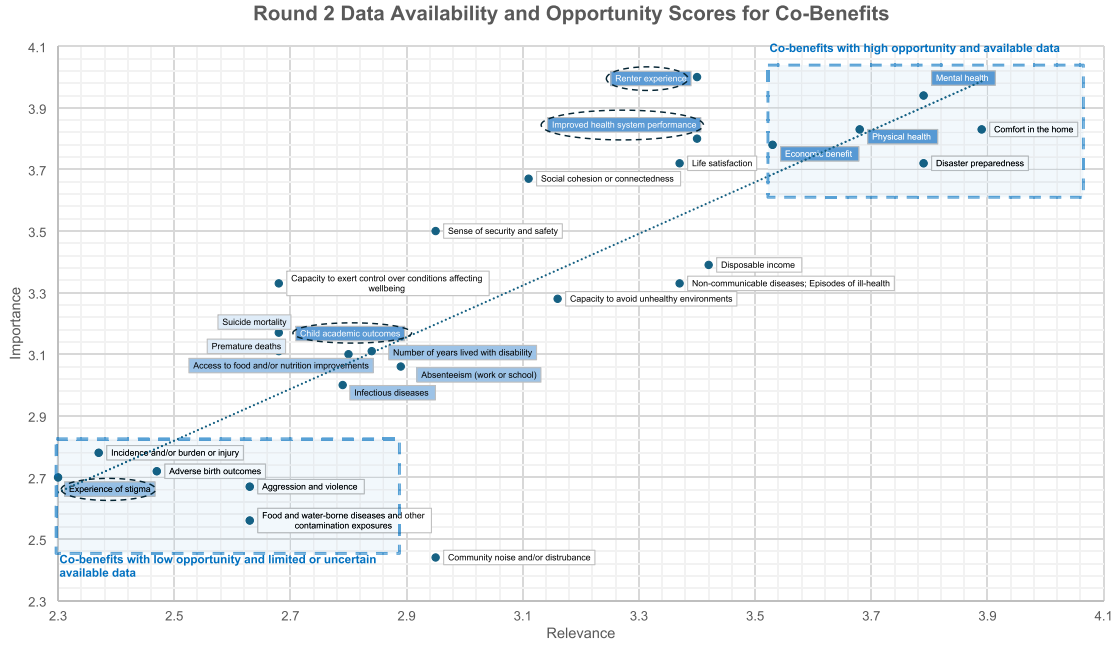

Figure 4. Opportunity and data availability for co-benefits. Figure depicts a scatterplot of opportunity, showing mean scores for relevance (*x*-axis) and importance (*y*-axis). The Pearson correlation co-efficient for likelihood x data availability and importance x data availability are 0.59 ($p < 0.01$) and 0.73 ($p < 0.01$) respectively. Each co-benefit is represented by a shortened label (see key for figure 3) and is color coded according to mean data availability: available (darker blue), uncertain (middle blue), and not available (pale blue).

Experts thought about co-benefits in terms of specific causal pathways, wherein a certain policy or programme can lead to a given set of co-benefits by changing specific environmental or other living conditions. The way in which a policy or programme may change these conditions seemed to affect what co-benefits they considered likely or important. For example, one expert explained that:

'*…an improvement in thermal comfort is likely to be accompanied by a reduction in stigma and an increase in social inclusion and belonging*' and that '*… these characteristics have been shown to have a causal influence on student academic and related outcomes*'.

Some experts also discussed the potential for 'knock-on' effects in which the impact of policies or programmes appear to have additional co-benefits that flow on from the primary outcome of interest in a cascading manner.

For example, one expert identified that a benefit of climate action is the

'*…community influence/positive growth of energy efficiency measures by proximity/visibility of energy efficiency improvements for neighbors*'.

Another key theme within the open text responses was the consideration of how co-benefits could be measured and potential poor data quality, lack of specificity, and practicalities of using available data. This was an important concern for some of the experts, with the level of clarity on related data availability and methodology varying significantly. Some experts cited their own projects or indicators they use to suggest

potential solutions or ways forward in evaluating co-benefits, whereas others were concerned that quality data may not exist for certain variables. Uncertainty around data availability seemed more applicable to variables or co-benefits that were traditionally more 'qualitative' (e.g. social equity), and clearer methods for measuring and obtaining data existed for clinical health outcomes and customer satisfaction for example. When asked to comment on the data availability of each listed co-benefit individually, some of the experts repeated answers across different co-benefits which highlights that existing datasets may have broad applicability across a range of co-benefit measures.

5. Discussion

A two round Delphi Survey was conducted to: (1) identify health and wellbeing co-benefits of climate change adaptation and mitigation; (2) assess their perceived relevance and importance to policy and programme evaluation; and (3) identify data available to measure these co-benefits. Senior experts from a diverse array of Directorates with unique backgrounds in policy and programme development and/or implementation participated.

Overall, there was positive appraisal of co-benefits in terms of their relevance and importance to policies and programmes. Co-benefits that were rated as having greater relevance were generally rated as having higher importance. This reflects existing literature that suggests that factors of issue salience, familiarity, and personal relevance have an important role in shaping policy actors' perception of the importance of an issue, as well as citizen motivation and participation in policy issues (Moat *et al* 2013, Lee *et al* 2017). Agreement observed in Round 2 demonstrated strong consensus for co-benefits that were rated as relevant and important. For example, for the top five co-benefits based on opportunity scores (mental health, comfort in the home, disaster preparedness, physical health, and economic benefit), agreement with importance scores was 100% and agreement with relevance scores was between 80%–100%. All top five co-benefits therefore met the threshold for a high degree of consensus (>75%). Similarly, the two co-benefits rated as not relevant (incidence of adverse birth outcomes, and incidence and/or burden of injury) and the co-benefit rated as unimportant (community noise and/or disturbance), had an agreement of 90% in Round 2. Analyzing these results together, they indicate a high degree of consensus for co-benefits that are highest and lowest priority for policy and program evaluation across a range of climate change interventions and Government directorates. Greater levels of agreement and consensus for elements considered highest priority have also been found in other studies (Byrne *et al* 2020, Verweij *et al* 2023).

Co-benefits that were rated as having neutral relevance and/or importance showed a greater range of agreement between 30–90%. Many of these co-benefits are sub-sets of the top five co-benefits. For example, suicide mortality may fall under the broader umbrella of mental health, and infectious disease and premature deaths may be viewed as a sub-set of physical health. As we looked at climate change policies and programmes broadly, it may be that the top five co-benefits have greater generalizability and relevance, while 'neutral' co-benefits may be more specific to certain policies and programmes and not be rated as consistently high as their 'umbrella' co-benefits. It is also possible that the perceived neutrality of many of the co-benefits may have resulted from the high degree of diversity in participants' area of expertise. For example, an expert considering transport policy may perceive a co-benefit of reduced injury as highly relevant or important but another expert considering energy efficiency measures in homes may find such a co-benefit much less relevant and important compared to increased disposable income, leading to a 'crossing-out' effect (Chapman *et al* 2018, Jennings *et al* 2020, Filigrana *et al* 2022). Whilst the perceived neutrality of many of these co-benefits indicates that more context and program specific evaluations are necessary, the high degree of agreement across the 'umbrella' co-benefits suggests that future studies or evaluations should still consider these broad categories of co-benefits as having general relevance and importance across programs and policies. It should be acknowledged however, that due to the deliberate anonymous approach employed for the survey rounds, we could not assess individual stability in survey responses. Significant opinion changes between survey rounds once they reviewed the whole panel's controlled feedback and what biases or other influences this may have had, especially from certain policy sectors and for more sector specific 'neutral' co-benefits, was not assessed (Holey *et al* 2007). In turn, while we have assessed the level of agreement on the importance and relevance of co-benefits, we did not assess convergence in the understanding of these co-benefits, which limits our capacity to understand why co-benefits such as 'reduction in stigma' for example had such a low opportunity score despite mental health and wellbeing being ranked as one of the top co-benefits and the clear link between the two that was established in the qualitative responses. Despite this limitation, the purposeful diversity of the panel in terms of policy sector was ultimately a strength of the study as it allowed for a wide range of co-benefits to be assessed, thereby achieving the main aim of our study. Due to this diversity however, we did not explore temporal considerations for the co-benefits or provide any baseline time periods for comparison. This should be pursued in policy or programme specific research,

especially to account for differentiation in the perceived relevance, importance and data availability for co-benefits that may be accrue over the life course and are harder to evaluate (Becvarik *et al* 2024).

Qualitative analysis from Round 1 supported the quantitative results, highlighting that experts considered a broad variety of wellbeing co-benefits. Most of the additional co-benefits identified by experts related to social, behavioral, educational and equity outcomes; and are supported by existing literature. For example, home energy efficiency improvements have been shown to reduce the number of days children with asthma are absent from school which can have a meaningful impact on educational outcomes (Howden-Chapman *et al* 2008). The qualitative results also indicated that experts typically thought about co-benefits along causal pathways with cascading knock-on effects which were dependent on how the policy and/or programme changed environmental or other conditions. This highlights that the experts' conceptualization of co-benefits aligned with working definitions and theories in the literature that emphasize the interconnectedness and importance of environmental, living, and social conditions (Liu *et al* 2016, Hiscock *et al* 2017, Jennings *et al* 2020).

The top co-benefits in our Delphi study broadly relate to the most common concerns and/or areas of reporting found in other studies (CDP 2020, Jennings *et al* 2020, Sharifi *et al* 2021). For example, research mapping the co-benefits of climate change action to issues of public concern in the UK identified that the main issues of public concern (and therefore associated co-benefits) related to health, security, economic and employment conditions, poverty, housing, and inequality (Jennings *et al* 2020). These broadly align with some of the top ten co-benefits identified in our Delphi study. For example, comfort in the home, physical health, health system performance, renter experience, and disposable income all relate to these broad categories. The work by the 'Global Adaptation Mapping Initiative' also outlines common health outcomes reported for adaptation to climate change which include both direct and indirect health outcomes identified as co-benefits in our Delphi such as reduction in infectious disease incidence, improved access to water/sanitation and improved food security (Scheelbeek *et al* 2021). Furthermore, through the Carbon Disclosure Project (2020) cities across the Asia Pacific, Europe, and North America that have reported co-benefits of climate action have identified co-benefits including improved public health, improved resource quality and security (e.g. energy and food), enhanced resilience (e.g. to shocks such as floods), and social community improvements. These overlap with our top ten co-benefits such as physical health, disaster preparedness, and social cohesion and connectedness, as well as lower rated co-benefits such as access to food and nutrition improvements. Interestingly, disaster preparedness, which was rated as relevant and important in our Delphi study, has also been included in the CDP-ICLEI Unified Reporting System as a co-benefit of climate mitigation but is not commonly reported by participating cities, especially in high income countries (CDP 2020). These findings suggest that, whilst this Delphi study was conducted among Government experts in the ACT, the identification and prioritization of co-benefits by these experts have wider global relevance and align with current trends in both research and governance. However, it is important to caution against over-generalizing the results in other contexts or across all policies and programmes, as there may be critical differences between policies, sectors, and geographic locations that are not represented by the ACT-based case study (Becvarik *et al* 2024). For example, variation in the co-benefits reported across regions highlights important differences in both prioritization and data availability which may be best addressed by an international Delphi (CDP 2020).

The final list of 28 co-benefits in our Delphi study was collectively informed by a literature review, an expert workshop, and the survey rounds; with agreement rates from the Delphi providing a guide to priorities the list. The wide-range of co-benefits identified, and the consideration of complex cascading pathways observed in the open-text responses, highlights the importance of the approach. Furthermore, removing co-benefits would limit the transferability and utility of the list to other contexts where it could inform place-based prioritization. Inclusion of all 28 co-benefits also enables assessment of perceived data availability and gaps in access or quality that may impact monitoring and evaluation efforts across all sectors. Other studies focused on identifying and prioritizing items have also not removed items between survey rounds for similar reasons (Byrne *et al* 2020, Verweij *et al* 2023). It is also important to acknowledge here that the co-benefits that were low in consensus were included in the list presented to experts because they were previously identified in the literature or by experts themselves in the workshop or the first Delphi round. Just because they lacked the same level of consensus as the top co-benefits does not automatically lower their value for certain policymakers or the attention warranted in further research. Instead, it provides evidence that more policy specific and targeted research amongst a single sector of experts may be required to reach consensus or gain insight on these co-benefits, similarly to those found to be of 'neutral' relevance or importance.

Less than half (43%) of the 28 identified co-benefits have available data based on experts' knowledge working in the ACT. When assessing data availability together with opportunity scores, the relationship was positive and statistically significant. Co-benefits with high opportunity and data availability represent the

'low-hanging fruit' that may be more readily integrated into policy or programme evaluation. However, this may also reflect how existing data availability may bias what co-benefits are seen as relevant or important. This could include an availability bias or heuristic for example, wherein that which is more easily accessible or more familiar is recalled more readily or considered more important (Kynn 2008, Little *et al* 2018).

Quantitative and open-text responses across both Delphi rounds highlighted that data availability and the measurement of co-benefits are areas of concern and interest for many experts, with potential limitations in data quality. This reflects existing literature which indicates a key gap in the availability of data and clear indicators to evaluate co-benefits, as well as inadequacies in data quality relating to accuracy, appropriateness, and data resolution (Sharifi *et al* 2021, Bhat and Farzaneh 2022, Ommer *et al* 2022, Fernandez-Guzman *et al* 2023). In Round 2, whilst all co-benefits had agreement scores over 50%, there was no clear trend between data availability and the degree of agreement. The mixed results for agreement with data availability scores may reflect that awareness and knowledge on data availability and how to apply datasets for evaluating co-benefits may still be developing in line with increasing interest, and that experts may perceive greater data availability for co-benefits they are most familiar with (e.g. those that are relevant to their specific area of expertise). This aligns with existing literature on measuring co-benefits, finding that data availability tends to be more advanced for indicators that have been more frequently used historically (e.g. biophysical indicators of nature-based solutions), as opposed to other socio-economic or wellbeing indicators (Ommer *et al* 2022). In turn, the mixed results for agreement with data availability scores may also reflect a lack of inter-directorate understanding and knowledge of data sets that can result due to siloed working culture and a lack of consistent standards for recording and accessing data across government (National Audit Office 2019, Domeyer *et al* 2021). The findings of this study therefore lend support to the utility and need for a central repository or greater data sharing mechanisms across government directorates. Furthermore, high levels of agreement on the lack of data availability or uncertainty for some co-benefits, such as the burden of injury and aggression and violence, highlight the need to focus efforts towards measuring broader co-benefits and identifying datasets and indicators that would facilitate this. However, as indicated by experts in their qualitative appraisal, even if there is data available, the quality and type of data may severely constrain or strengthen capacity to evaluate co-benefits for real-world policies and programmes. We asked the simplified question of whether there was existing data available to measure the co-benefit, but future research and appraisal of data needs to question what that data can do (e.g. is it longitudinal and appropriate for causal analysis or is it available at appropriate geography to conduct correlations across areas where a policy has been implemented), as well as additional data requirements such as whether there are valid estimates of the impact of a policy or programme on a co-benefit (e.g. number of hospitalizations avoided) or known trade-offs or co-harms of adaptation (Scheelbeek *et al* 2021, Becvarik *et al* 2024).

6. Conclusions and recommendations

The findings of this study offer insights into which health and wellbeing co-benefits of policies and programmes are of greatest relevance and importance to government experts, as well as which of these may be more easily integrated based on data availability. The list developed through this methodology has broader policy utility in that it presents a diverse array of co-benefits that can be prioritized by specific policy sectors, and highlights the shared benefit for health and the environment in strategically evaluating and reporting co-benefits over the long-term. Furthermore, the strong agreement on the top 5 co-benefits of reduced mental health burden, increased comfort in the home, improved disaster preparedness, improvement in physical health, and economic benefits from averted healthcare costs; suggests an overlooked value prospect of climate policies. Ongoing data availability challenges, however, limit the ability to quantify this value and highlight the need for improved availability of quality data and knowledge sharing. Prioritizing data availability will also help limit potential evaluation bias and elucidate unidentified value of co-benefits, particularly those rated as having neutral relevance or importance in this study. Further research to identify, measure and evaluate co-benefits will be integral to effectively addressing environmental and climate change, whilst improving and protecting health and wellbeing. A critical focus in this future research should be to build on the findings of this Delphi study in order to develop a standardized methodology to measure co-benefits, as well as advance methods of valuing co-benefits in the face of data limitations.

Data availability statement

The data cannot be made publicly available upon publication because they contain sensitive personal information. The data that support the findings of this study are available upon reasonable request from the authors.

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Ethical Statement

This research was conducted in accordance with the principles embodied in the Declaration of Helsinki and in accordance with local statutory requirements. All participants gave written informed consent to participate in the study and the ethical aspects of this project were approved by the Australian National University Human Ethics committee (Protocol H/2023/1275).

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