Multi-criteria assessment of household preferences for reducing greenhouse gas emissions: an analysis of household survey data from four European cities

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ABSTRACT
(n=190)

In a study of households living in mid-size cities in France, Germany, Norway and Sweden we assessed preferences (among 65 possible actions) for reducing greenhouse gas (GHG) emissions. Each GHG reduction action was compared in terms of three objective criteria – CO_2e emissions, health impact and cost – using scores which gave alternative priority weightings to each. The multi-criteria scores were then compared with the proportion of respondents declaring their willingness to implement each action. Actions that respondents were often willing to implement and scored highly on the three assessment criteria included measures with likely ancillary benefits for health such as eating 30% more vegetarian food, walking and cycling instead of using public transport, and improvements of roof and window insulation. Although most householders appeared willing to make appreciable changes to their lifestyle and home in order to help achieve GHG emissions reductions, relatively few signaled their willingness to adopt major changes, such as becoming entirely vegetarian or giving up use of the car, even if there were appreciable health benefits. The evidence of these analyses provides insights into household preferences for actions that may help achieve important mitigation and health benefits.

Keywords: climate change, mitigation, household actions, multi-criteria analysis, health co-benefits

Abbreviations

CO_2e – Carbon dioxide equivalents in terms of greenhouse gas potential

HOPE – Household Preferences for Reducing Greenhouse Gas Emissions in four European high-income countries.

BACKGROUND

It is now well understood that meeting climate change mitigation targets requires rapid and transformative actions by populations in countries across the socio-economic spectrum.[1] [2] [3] The aspiration to limit climate change to a global average temperature rise of no more than 1.5°C above pre-industrial levels, as declared at the 2015 Paris conference of the United Nations Framework Convention on Climate Change,[4] implies particularly urgent action.[5,6] Under business as usual development, cumulative emissions of Greenhouse Gases (GHG)* are expected to exceed allowable limits within a decade or so.

Responsibility for achieving the required reductions will require collective action at international, national and subnational levels. Actions by individuals with respect to their lifestyles and homes are also crucial, both with respect to autonomous and 'voluntary' actions, as well as actions that are governed by public policies. A cardinal challenge is how to encourage or compel individuals (using the 'carrot' and the 'stick') to adopt changes of the needed pace and scale. Developing evidence to inform policymakers on how to achieve such changes is the principal aim of the HOPE project (*Household preferences for reducing greenhouse gas emissions in four European high income countries*),[7] which has undertaken assessments of a range of household actions focused on climate change mitigation. Its specific focus is on the potential importance to householders' decisions of information on the impacts on health of such actions, as well as on carbon emissions. Most research in this area has focused on such questions as the public acceptability of mitigation policies,[8] the theoretical emissions reduction potential of selected lifestyle or consumption choices,[9] [10] the impact of behavioural choices (with and without the 'rebound effect'),[11] citizens' general preferences for tackling climate change,[12] and the willingness to bear extra household expenditure to support carbon reduction.[13]

The evidence is now clear that many actions are likely to have direct positive impacts on health – actions such as adoption of more sustainable diets,[14] [15] [16] home energy efficiency improvements,[17] [18] changes in travel behavior.[19] [20] But while an increasing number of studies has focused on the relevance of health co-benefits to macro-level policy,[21] [22] [23] [24] fewer studies have focused on their relevance to householders' choices.

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* Throughout this paper we use the term GHG (greenhouse 'gases') (IPCC 2014) which refers to gases as well as solid particles that contribute to the greenhouse effect by absorbing infrared radiation. A technically preferred, but less commonly used, equivalent term is "Climate active pollutant" (CAPs), which recognizes the fact that not all GHGs are gases. CO_2e (e for equivalent) refers to the global warming potential of all CAPs/GHGs in terms of their equivalence to CO_2.

In this paper, we present analyses of data from the HOPE study which evaluated household actions with regard to three objective dimensions of impact (CO_2e reduction, health, cost) as well as the correspondence between objective assessment of the priorities for action and the stated willingness of respondents to implement the required changes.

METHODS

The HOPE study entailed three sets of data: (1) a survey, conducted between May and October 2016, of households from cities and surrounding areas in four European countries: Bergen (Norway), the Communauté du Pays d'Aix (France), Mannheim (Germany) and Umeå (Sweden); (2) a qualitative interview of a sub-sample of the households that took place in the survey; and (3) an assessment of current climate policies in the four involved countries. Further details of the study protocol are given in *Herrmann et al* 2017.[7] This article rests mainly on the data from the survey.

The study sample was drawn to ensure representation with respect to, geographic location (city centre, suburbs, rural), type of household livingg (collective, individual), presence of children (<18 years), housing tenure (owner-occupier, renter), age group (18-65, 65+). The samples for each location achieved a reasonably good spread with respect to these and other assessed characteristics, including household size, income and educational attainment, and, on the whole, achieved a reasonable frequency of households in each category of these variables by comparison with the national distribution (though of course not mirroring the national distributions precisely).

For each household, an assessment was made of each of 65 prescribed actions, listed in Table 1, with potential for reducing the GHG emissions. The actions were chosen by the research team to be reasonably inclusive (though not necessarily exhaustive) of the principal household activities associated with appreciable greenhouse gas emissions in four areas of household consumption: housing, food (including waste), mobility and other consumption. In total, data were obtained from 309 households: 70 (22.7%) from Aix, 107 (34.6%) from Mannheim, 58 (18.8%) from Bergen, and 74 (24.0%) from Umeå. For each household, we assessed each of the possible mitigation actions with regard to the following parameters:

(1) Potential for GHG reduction

This assessment was based on a carbon footprint calculation and simulation (FCS) tool developed for the project, which was populated with details,

obtained by online questionnaire (or, where necessary, a paper version), of household consumption patterns and spending in the four sectors of: housing, food, mobility and other consumption.

The FCS tool was used to calculate the initial carbon footprint of the household and to simulate the reduction of GHG emissions in kilogrammes CO_2-equivalent (CO_2e) per year expected from implementation of each of the 65 mitigation actions. Following the definition of Wiedmann and Minx,[25] we considered a household's GHG emissions to include all emissions directly or indirectly caused by the household's activity in one year. The FCS-Tool computed the greenhouse gas emissions of consumption behaviour using methods that combined different data sources. For instance, for transport emissions, the kilometers of car use per year were multiplied by the corresponding emission factors (e.g. CO_2 emissions per kilometer for the relevant car type) taken from a common database (the IMPACTS database of the French Environment and Energy Management Agency). For electricity, emission factors (per kWh of consumption) were based on data on the national energy mix.

All calculations were tailored to the specific circumstances of the household, including the size and thermal properties of the dwelling, dietary patterns etc. GHG reductions actions that did not apply to a particular household, such as meat reduction in vegetarian households, were marked as not applicable. Further details of the FCS tool, its calculation methods and values used for the emissions associated with particular food types and consumer goods will be given in Dubois *et al*.[26]

(2) Cost

The cost (Euro or Kroner per year) of each action was assessed up to a 15-year time horizon (to 2030) and was calculated in terms of (i) changes in capital investments, calculated as a monthly equivalent cost (saving) and (ii) changes in recurrent expenditure, e.g. from changes in fuel bills, transport costs etc. We assumed a discount rate of 3%, consistent with the range of discount rates used in European countries in health technology assessments.[27] We used a time horizon of 2030 for consistency with the simulation of 50% reduction by that date, and because 15 years is broadly the replacement cycle of household interventions with longer replacement cycles, such heating systems and glazing.

(3) Health impact

Several of the mitigation actions have probable positive or negative effects on health, largely arising from changes in diet, physical activity or exposures in the indoor environment (temperature and air quality). We quantified these impacts using a semi-quantitative five-category scale: a small negative effect, no impact, then small, moderate or substantial positive impact (+, ++, +++). As an approximate guide, a '+' impact was interpreted as being likely to result in <1 month change in life expectancy, '++' a 1-3 month increase, and '+++' >3 months increase. The classification was reached through expert judgement of team members using evidence of recent reported studies from broadly similar European populations. Such studies included assessments of the impact of dietary changes,[15 28] active travel[29 30 31] and home energy efficiency interventions.[17 18 32] We did not quantify the effect of actions that have sizeable impact only through collective effect when made by a high proportion of the population in a given area. Thus, we classified as negligible the consequences of an individual's travel behaviour to local outdoor air quality, and assessed the associated impacts only in terms of physical activity and road injury risks. This means that we underestimate an important benefit for health of selected mitigation actions (ones that result in reduced emissions of pollutants from fuel combustion),[33 34 35] which are small at the individual level.

(4) Declared willingness to implement each action

Among other information, the household respondent was asked to indicate his/her willingness to implement each of the 65 potential climate change mitigation actions relevant to his/her household. This was done using action cards to illicit a response on a five point Likert scale: 1=very willing, 2=willing, 3=neither willing nor unwilling, 4= rather unwilling, 5= unwilling. For analyses we used a further binary classification based 1 or 2 *versus* 3, 4 or 5 responses, and computed the proportion of all respondents answering 1 or 2 on the Likert scale.

Multi-criteria analysis

We assessed each of the mitigation actions with respect to the three dimensions of GHG reduction (in terms of CO_2e), health and cost using the analytical framework of multi-criteria decision analysis, except that we used permutations of criteria weights rather than weights determined through an independent elicitation process with each householder. (Such elicitation and the iterative feedback of multi-criteria results was not part of the study protocol, which was based on an alternative method of information

presentation and decision processes, described elsewhere.[7]) For each dimension, the impact of each action was first transformed into a response on a scale from 0 to 1.

For GHG reduction, the target impact was assumed to be 50% of the baseline carbon footprint for the household, a target chosen to reflect the likely minimum pace of emissions reduction consistent with the Paris agreement. The current EU climate and energy framework contains a binding target to cut emissions in the EU territory by at least 40% below 1990 levels by 2030.[36] But unless substantial negative emissions are invoked, limiting the increase in global mean temperature to 1.5 degrees Celsius above pre-industrial levels is likely to require more ambitious action that reduces emissions to very low levels by around 2030.[37] [38] [39]

Each intervention was thus classified with respect to its potential contribution to the achievement of the 50% reduction. Note that actions likely to have adverse impacts on greenhouse gas emissions for a particular household were not considered further as they do not represent options for reducing GHG emissions.

For the cost dimension, we summed for each household the total cost of all 65 actions, separately summing actions that represent a cost saving from those that represented additional cost burdens. The range of these two quantities (i.e. the sum total of potential savings through to the sum total of potential costs) was used as the range against which individual actions were assessed. A zero cost action was represented by a point close to the middle of this range, with cost savings represented by a translation in one direction and additional costs in the other -- all mapped onto a 0 to 1 scale. We used 1 to represent maximum obtainable cost savings and zero as the maximum possible additional cost burdens.

For the health dimension, the five point categorization was mapped onto the 0-1 interval as follows: 0=small adverse effect, 0.25 zero effect, 0.5=small positive effect, 0.75=moderate positive effect, 1=substantial positive effect. Out of the total of 65 climate change mitigation actions, we classified only 12 as having a non-trivial health effect for the individual (see Herrmann *et al*[7]).

A multi-criteria score was then calculated for each action based on a weighted average of its impact (measured on the 0-1 interval) on each of the three dimensions. The relative weights given to each dimension were varied to assess their influence on the relative position of one action against another. In the results shown in the graphs below, we present result relating to two sets of weights: (i) where all three dimensions were given equal weight, (ii) where the weights for CO_2e, health impact and cost saving were applied in

the ratio of 1:2:3 (which broadly reflects the order of importance many attribute to these dimensions in household decisions[40]).

RESULTS

The results for the multi-criteria scores for each of the mitigation actions are shown in Figure 1 for a range of alternative weights for CO_2e reduction, health impact and cost. In this and subsequent figures, the dots represent the mean estimates per mitigation action across the 309 households (respondents), and the vertical lines show the interquartile range.

The graph of panel [A] shows the results with equal weight given to each of the three criteria, but the relative rankings are very similar with each of the alternative permutations, as shown in Panels [B] to [G].

Most of the actions end up with a very similar score (in the range 0.2 to 0.3 for the equal weight plot), signifying broadly similar impact on the basis of the multi-criteria score. However, there were two groups of actions with appreciably higher scores. The first group was actions reflecting dietary changes (specifically changes oriented towards increasing vegetarian foods and reducing dietary meat) and giving up pre-prepared 'ready meals'. The action with the overall highest score was that of becoming vegetarian, followed, in descending order, by actions to increase vegetarian food by 60%, then 30%, and then giving up ready meals.

The second major group of high score actions was that of travel-related changes, specifically actions aimed at reducing use of private motor vehicles overall or through a switch towards use of public transport and also the use of walking and cycling instead of public transport. Giving up use of a car altogether was estimated to have an impact score comparable to that of a largely vegetarian diet.

Somewhat lower than the impact of these two groups of actions, but still above the main group of other mitigation actions (except where health was given the lowest weighting), were actions to improve the thermal efficiency of the dwelling. In particular, improvement of roof insulation and replacement of windows with improved thermal efficiency (new double or triple glazing) both had relatively favourable scores, with wall insulation somewhat lower.

One measure, notably action to reduce (heating season) indoor temperatures by 3°C through re-setting of thermostatic control, had a low score, despite being both a cost saving measure and one that reduces greenhouse gas emissions. This largely reflects the fact that it is estimated to have an adverse effect on health (and thermal comfort).

The use of alternative weightings did not appreciably alter this general pattern across the spectrum of mitigation actions. But the health weighting (more than that of either of the other two criteria) was influential in giving a clear separation of selective actions from the relatively tight cluster of the majority of actions under most permutations of criteria weights. Actions towards a vegetarian diet and reduced use of motor travel both stand out as priority targets, with home energy efficiency in the second tier (except when health was ranked lowest).

Comparison with willingness to implement actions

Figure 2 shows the action ratings relative to the proportion of respondents who indicated that they were willing or very willing to implement the required change. The dotted red line indicates the proportion 0.5, so all actions to the right of this line are the ones for which more than half of respondents indicated that they were willing or very willing to implement the required change.

Actions that had both a favourable objective multi-criteria score *and* have a high proportion of respondents who are willing to implement the change are represented by the points in the top right of the graph. These include *moderate* shifts towards a more vegetarian diet (eat 30% more vegetarian food, action 28) and to give up ready meals (action 31), as well as again *moderate* changes to travel behavior, specifically walking or cycling instead of using public transport (action 39). Note that the action to shift more than 30% of journeys from car to public transport, action 38, and actions to reduce motor transport overall, all fell to the left of the 50% proportion being willing or very willing. Action to change to the thermal efficiency of the dwelling also achieved fairly high 'willingness' ratings, but was still rated as willing or very willing to adopt by less than 50% of respondents (households).

Actions that have a high proportion of respondents who are willing to implement the change *even though they lack* a high objective multi-criteria score are represented by the points in the bottom right of the graph. These include eco-driving, recycling (30%) more waste, and buying more energy efficient devices.

Actions that have a high multi-criteria score but most households are unwilling to implement, are represented by the points in the top left of the graph. Respondents were generally unwilling to take actions that represented substantial shifts to their current lifestyle. For example, a low proportion of respondents indicated that they were willing to become entirely or largely vegetarian (actions numbered 30 and 29 respectively), or to give up the use of their private motor vehicle altogether (action 43) or even to reduce motorized travel by 30% (action 42).

Actions that do not have a high objective multi-criteria score *and* have a low proportion of respondents who are willing to implement the change are represented by the points in the bottom left of the graph. These include reducing leisure time or holiday activities, and reducing indoor temperatures by 3°C.

Figure 3 shows variants of the plot of Figure 2 with permutations of the criteria weightings. In parallel with the plots of Figure 1, they indicate that the broad patterns are largely invariant to the weightings applied. But of the three criteria, the weighting for health impact gave the greatest separation of selected actions from the main body of actions, while those for cost and CO_2e savings appear to be relatively unimportant.

DISCUSSION

The analyses in this paper indicate how household choices of different mitigation actions are affected by three separate dimensions of impact: CO_2e emissions, health and cost: CO_2e reduction, health impact and cost. The results combine evidence of those impacts using the analytical methods of Multi-Criteria Decision Analysis (MCDA), a technique used as a decision-support tool for policymakers and others.[41 42] They provide an insight into the household mitigation actions that appear most favourable not only on grounds of emissions reduction but also on grounds of health and cost, and thus are actions which objectively appear to be priorities for policy implementation. Although these analyses were not used interactively for discussion with householders, various messages appear to be clear.

First, several categories of intervention appear to stand out as ones with better-than-average impact. Those actions are the adoption of more vegetarian (and less meat-based) diets, reduction in dependence on motorized travel, and the improvement of the thermal efficiency of dwellings through insulation of the roof, walls and replacement of windows. All three of those measures have potential for appreciable impact on GHG emissions, but also carry potential benefits for health and are either cost saving, or entail only moderate additional cost once the return on investments is considered. The potential health benefits is particularly large for dietary changes and active travel (more walking and cycling over motor transport), both of which may reduce the risks of cardiovascular diseases and certain cancers, among other health effects.[24 22]

Second, which actions appear most favourable on objective multi-criteria assessment appears to be largely invariant to the exact weightings given to each component criterion. For example, broadly similar patterns are seen when equal weight is given to emissions reduction, health impact and cost as

when weightings are applied in the ratio of 1:2:3. The same types of action therefore appear to be good choices whatever the relative emphasis of different decision-makers, though the health criterion appears to be particularly influential in distinguishing some of the more favourable actions. (Improvements to the energy efficiency of the dwelling are not clearly distinguished from the pack when health is given the lowest weight.)

Third, despite evidence of good impact, analysing the Likert scale data indicate that householders are generally unwilling to make big changes to their lifestyle – but they are willing to countenance more moderate shifts, including in core areas of behaviour. Using the Likert scores on willingness to implement change, it is clear that the majority of householders are not willing to adopt an entirely vegetarian diet or to give up the use of their car. However, they are more willing to go part way and to consider moderate steps in the same direction – a partial substitution of meat with vegetarian food, and some reduction in overall use of motorized transport, as well as home energy efficiency and selective other improvements.

Thus, there are various actions which householders appear reasonably willing to adopt and which have potential for an important contribution to climate change mitigation. But the willingness to implement change seems to be limited where a large change is required, even if there is potential for appreciable health benefit (such as adopting an entirely vegetarian diet).

Our results also reveal those measures that households would be willing to implement, even though they do not score particularly highly against the objective criteria, such as ecodriving, or recycling more waste. These are particularly interesting measures since households seem to be willing to implement them simply because they are appealing to them. Hence, these measures might be promising candidates for public policies even though they may not yield as substantial change on objective criteria of benefit. On the other hand, there are measures that lack objectively high multi-criteria scores *and* lack households' willingness to implement these changes, such as reducing indoor temperature by 3°C.

With any exercise of this kind, there are of course various limitations and uncertainties. The multi-criteria scores are inevitably in part dependent on the method of problem-framing and calculation; there are unavoidable uncertainties and imprecision in the estimates of impact of each action on greenhouse gas emissions, health and costs; and the analysis was deployed not as an interactive tool for discussion with individual householders making real-life decisions, but as a more theoretical desk-based exercise – though simulations of changes in CO_2e emissions were done and used interactively with householders.

It would have been desirable to have been able to apply a more precise quantification of the health impacts of mitigation actions based on detailed analysis of dietary and lifestyle data for each individual. But that would have been a very complex undertaking beyond the time and resources available to us. Nonetheless, we believe our semi-quantitative approach provides a reasonable basis of classification as the approximate magnitude of impacts is fairly clear from other published studies.

Our assessment of health impacts did not include effects arising from collective actions that could lead to changes in, for example, ambient air quality. However, evidence from elsewhere suggests that such benefits are typically much smaller than those arising from changes in physical activity or diet,[29 24] for example, and they start to become appreciable only if contributing actions to are undertaken by a high proportion of households. We therefore did not feel it appropriate to include in the evidence presented to households benefits that are heavily dependent on the decisions of others, though we acknowledge that such benefits can be substantial at population level.

Recognizing these limitations, the particular value of our analysis is in highlighting those household actions that appear to be especially favourable for targeting based on the three dimensions of impact (CO_2e reduction, health impact and cost), and in showing the particular importance of health considerations in actions that relate to dietary change and active travel. Though many people appear unwilling to make large changes in household choices for climate change mitigation, the identification of factors that people often report willing to change suggests areas where efforts for change might be most likely to succeed. The health dimension appears to be an important part of that assessment for various actions.

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Authors' contributions

All authors contributed to designing and implementing the study. PW undertook the analyses and drafted the article; all authors commented on it and approved its final version.

Competing interests

None declared.

Ethics

The study was approved by the Institutional Review Board of the Medical Faculty, University of Heidelberg (S-611/2015), the Regional Ethical Review Board in Umeå (2015/357-31Ö), and the Norwegian Center for Research Data (44003).

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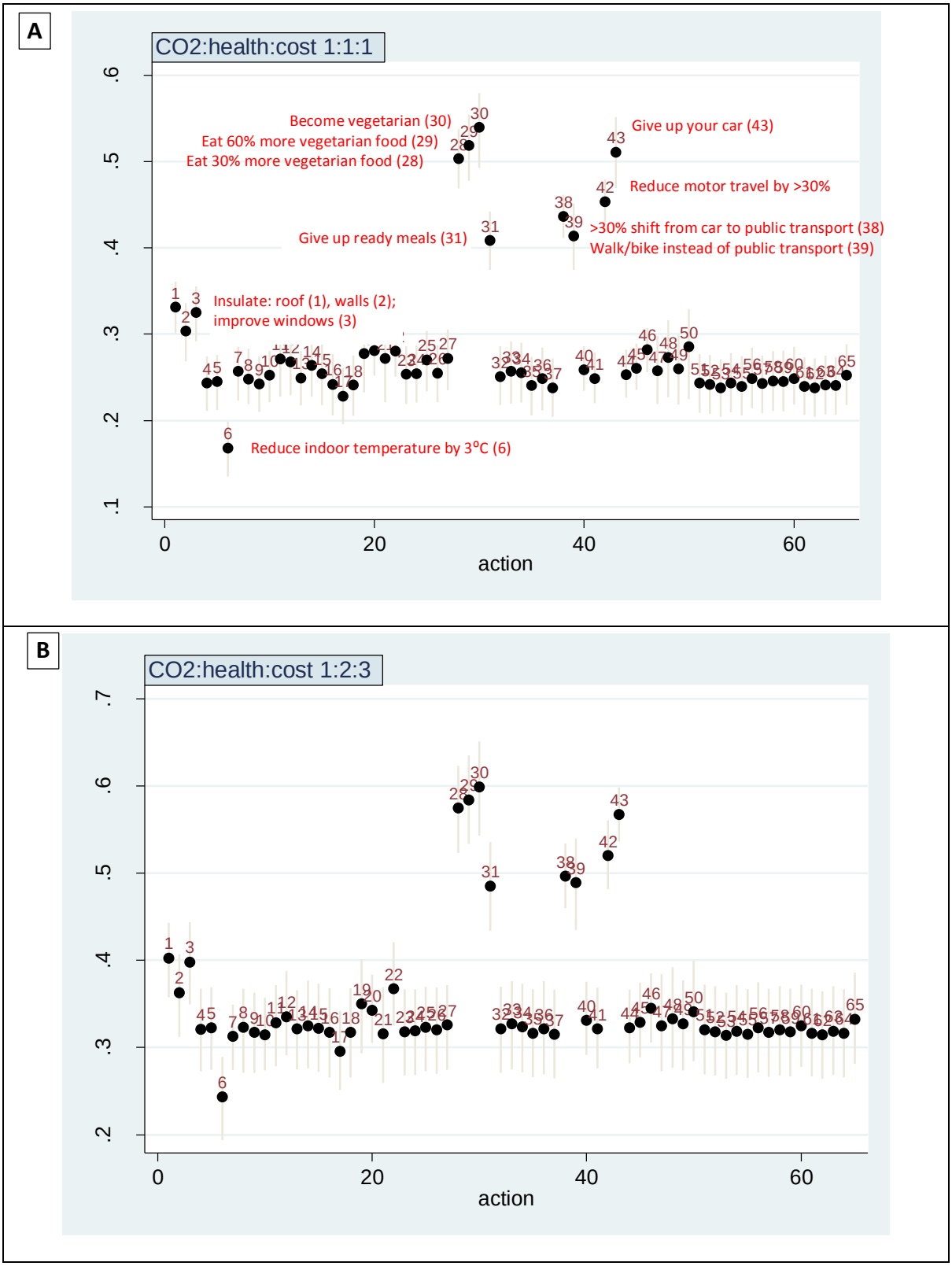
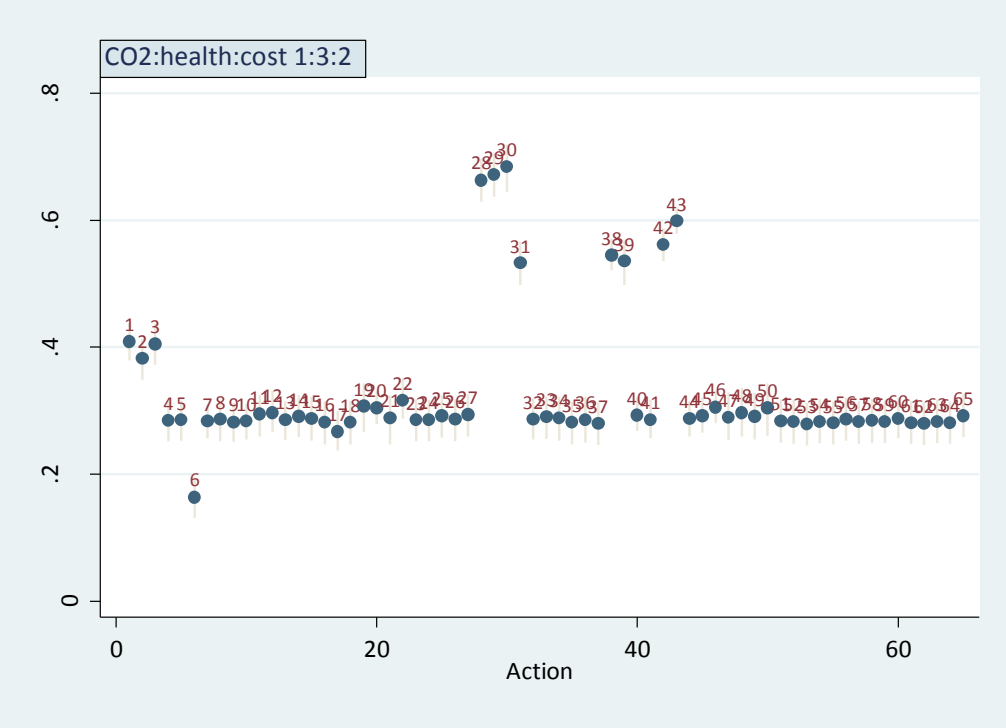
Table 1. List of evaluated household greenhouse gas (GHG) reduction actions.

Code	No.	Action
H1.1	1	Insulate roof / attic
H1.2	2	Insulate walls
H1.3	3	Improve windows
H2.1	4	Install an hourly thermostats
H2.2	5	Reduce indoor temperature by 1°C
H2.3	6	Reduce indoor temperature by 3°C
H3.1	7	Shift to energy efficient heat pump
H3.2	8	Shift to natural gas or biogas
H3.3	9	Shift to thermal solar collector for hot water
H3.4	10	Shift to thermal solar collector for heating and hot water
H3.5	11	Shift to wood/ pellet boiler as main heating source
H3.6	12	Shift to district heating
H3.7	13	Improve the energy efficiency of your heating systems
H4.1	14	Produce your own electricity (photovoltaic or wind mill system)
H4.2	15	Shift to a green electricity provider
H5.1	16	Use fewer devices and maintain them better
H5.2	17	Upgrade all of your home appliances to A +++
H5.3	18	Give up some of your appliances or share them with others
H6.1	19	Collective living: share your house with others
H6.2	20	Use more public transportation as a result of moving to the city center
H6.3	21	Buy and move to a low energy house (e.g. passive house)
H6.4	22	Buy and move to a smaller house/apartment
F1.1	23	Buy mainly fresh products, and give up deep-frozen and canned produce
F1.2	24	Buy at least 30% more locally produced food
F1.3	25	Buy at least 60% more locally produced food
F1.4	26	Buy at least 30% more organic food products
F1.5	27	Buy at least 60% more organic food products
F2.1	28	Eat 30% more vegetarian food (eat less meat and fish)
F2.2	29	Eat 60% more vegetarian food (eat less meat and fish)
F2.3	30	Become a vegetarian (stop eating meat and fish)
F3.1	31	Gradually give up ready-made meals
F3.2	32	Eat more eco-friendly food in restaurants and canteens
F3.3	33	Produce your own food
F4.1	34	Recycle 30% more of your waste
F4.2	35	Buy products with less or greener packaging

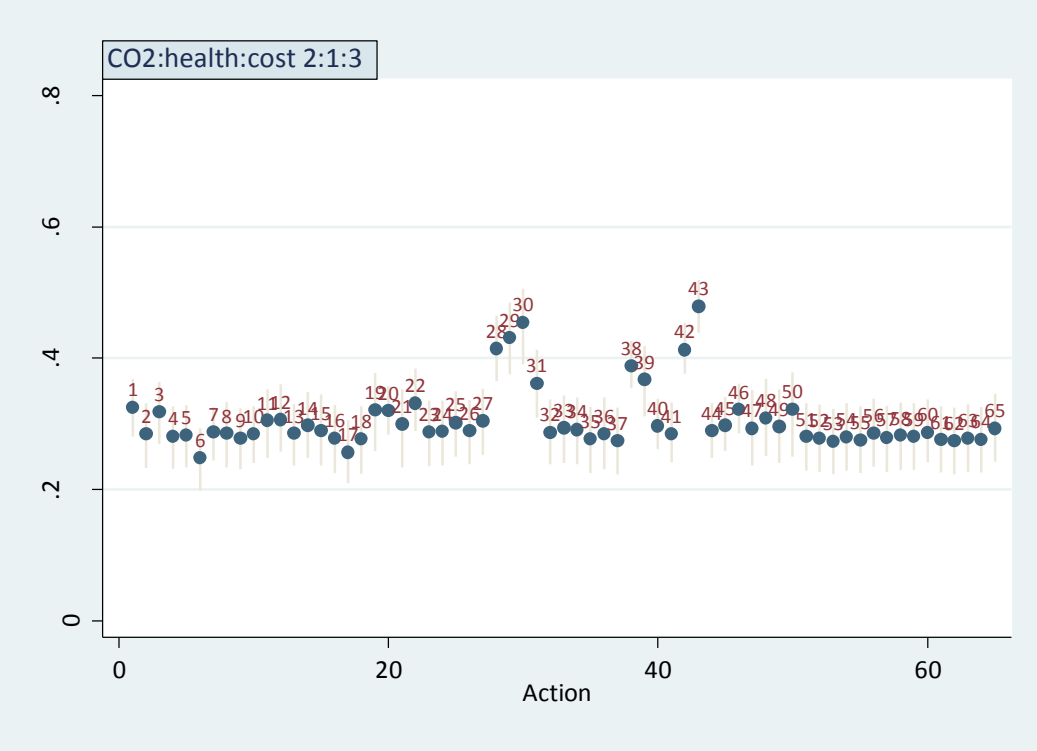
F4.3	36	Stop buying plastic and canned beverages
F4.4	37	Compost or recycle organic waste
M1.1	38	Shift significantly (more than 30%) from car to public transport
M1.2	39	Shift to non motorized modes of transport (walk, bike…) instead of public transport
M1.3	40	Use carpooling /car sharing for at least 30% of your current car mobility
M2.1	41	Eco-driving
M2.2	42	Decrease your travels with cars, public transports and other motorized vehicles by 30%
M2.3	43	Give up your car(s) and other motorized vehicle(s)
M3.1	44	Change to a smaller car (new or second hand)
M3.2	45	Change to a more eco-friendly car (hybrid, biogas, bioethanol, or electric)
M3.3	46	Change to a smaller AND more eco-friendly car
M4.1	47	Reduce your domestic and inter-European flights by 50% (substitute with train, boat, or car)
M4.2	48	Reduce your domestic and inter-European flights by 90%
M4.3	49	Reduce your inter-continental flights by 50%
M4.4	50	Reduce your inter-continental flights by 90%
C1.1	51	Buy 30% fewer clothes (repair, wait until damaged before changing)
C1.2	52	Buy 30% of your clothes second hand
C1.3	53	Buy 30% more ecological clothing (eco- and organic labelled)
C2.1	54	Buy 30% less cosmetic products (or create them yourself)
C2.2	55	Buy 30% more ecological cosmetics (eco- and organic labeled)
C2.3	56	Reduce your cosmetic and hygiene product consumption to the maximum
C3.1	57	Limit your use of internet (energy of servers, datacenters)
C3.2	58	Buy 30% fewer digital devices (give up or buy less)
C3.3	59	Buy more energy efficient devices
C4.1	60	Buy 30% less furniture and reduce your renovations by 50%
C4.2	61	Buy 30% more second hand furniture or build 30% of furniture yourself
C4.3	62	Buy 30% more eco-friendly furniture (eco-and organic labeled)
C5.1	63	Reduce your local leisure (cinema, theater, concerts) by 30%
C5.2	64	Choose 30% more eco-labeled holidays
C5.3	65	Reduce your holidays activities by 30%


A
CO2:health:cost 1:1:1
Become vegetarian (30)
Eat 60% more vegetarian food (29)
Eat 30% more vegetarian food (28)
Give up your car (43)
Reduce motor travel by >30%
>30% shift from car to public transport (38)
Walk/bike instead of public transport (39)
Give up ready meals (31)
Insulate: roof (1), walls (2);
improve windows (3)
Reduce indoor temperature by 3°C (6)
.1
.2
.3
.4
.5
.6
0
20
40
60
action
B
CO2:health:cost 1:2:3
.2
.3
.4
.5
.6
.7
0
20
40
60
action

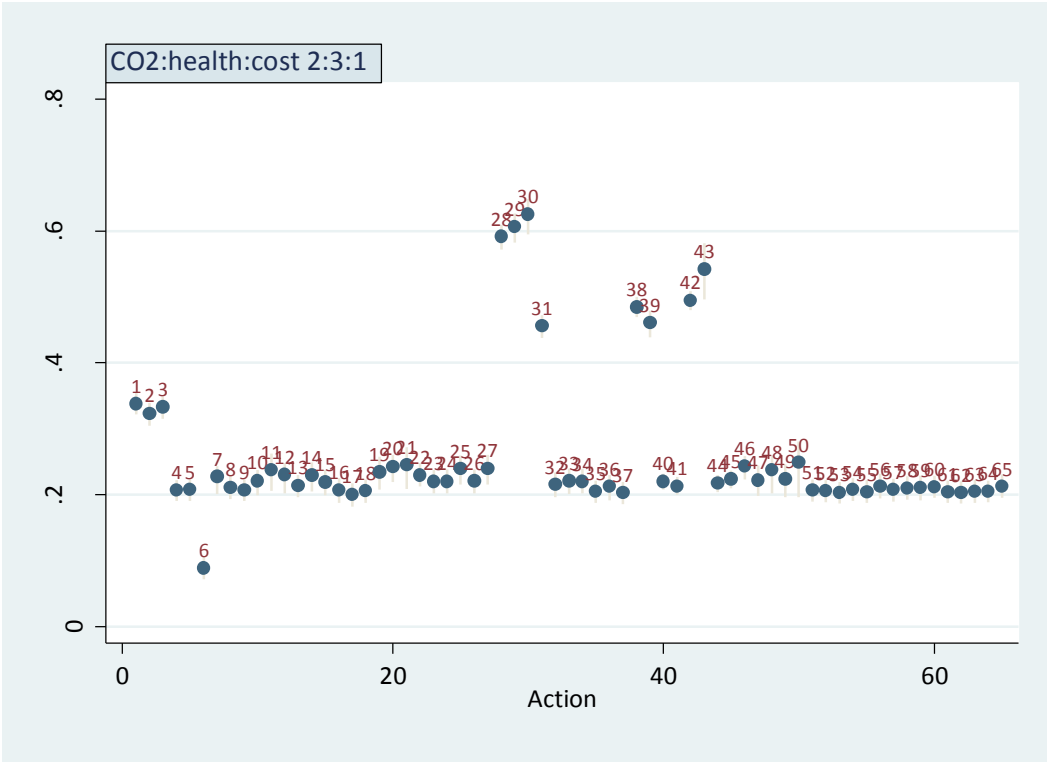
C


CO2:health:cost 1:3:2
0
.2
.4
.6
.8
0
20
40
60
Action

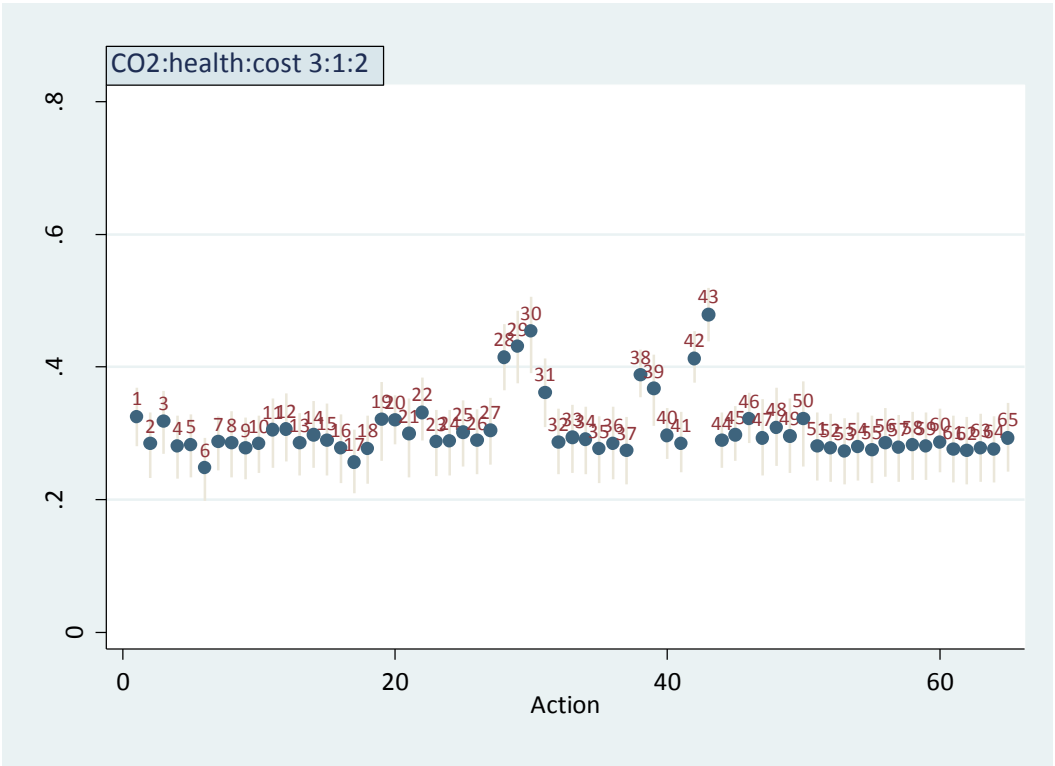
D


CO2:health:cost 2:1:3
0
.2
.4
.6
.8
0
20
40
60
Action

E


CO2:health:cost 2:3:1
0
.2
.4
.6
.8
0
20
40
60
Action

F


CO2:health:cost 3:1:2
0
.2
.4
.6
.8
0
20
40
60
Action

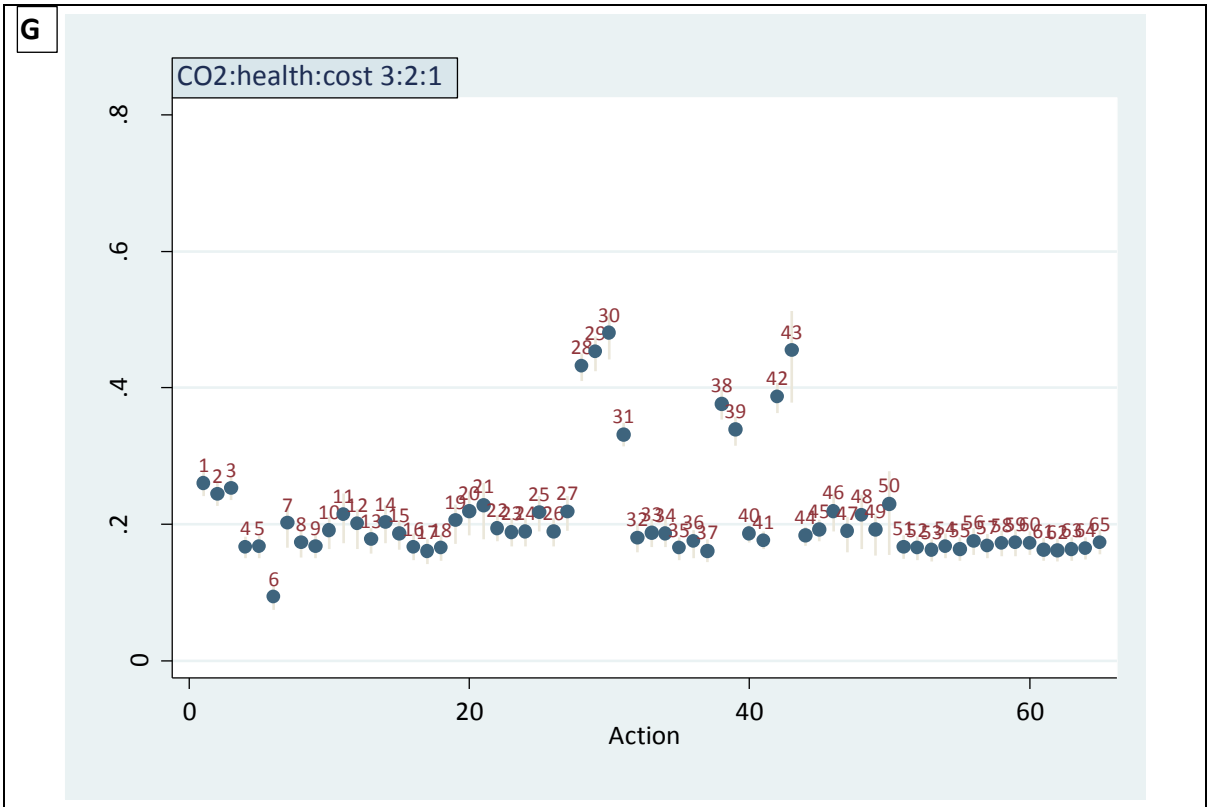


Figure 1. Multi-criteria scores of CO_2e reduction actions: mean and interquartile range for each of the evaluated household actions. Weights for $CO_2$2e, health and cost saving as follows: [A] 1:1:1 (equal-weighting), [B] 1:2:3; [C] 1:3:2; [D] 2:1:3; [E] 2:3:1; [F] 3:1:2; [G] 3:2:1. Actions are numbered as in Table 1.

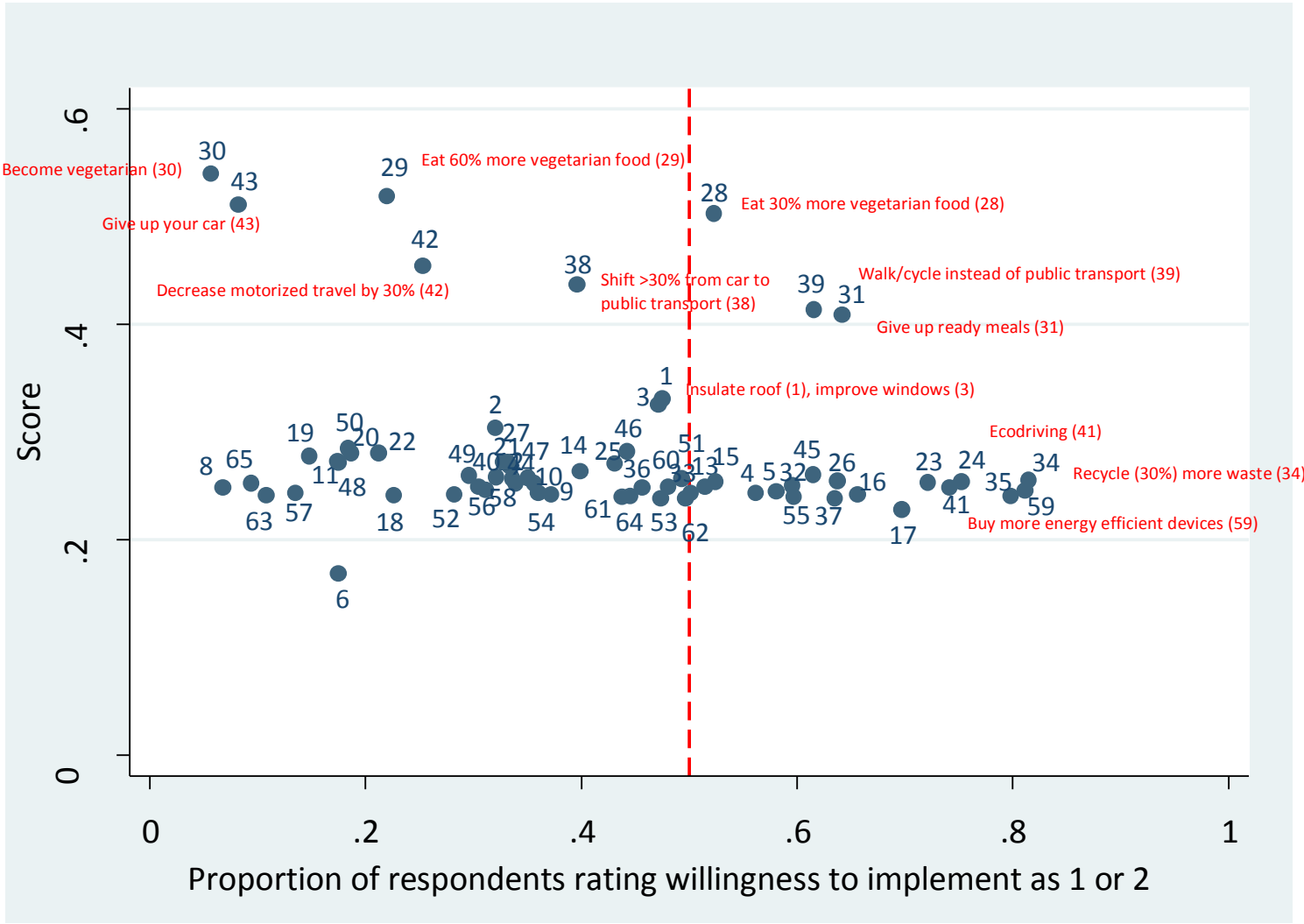
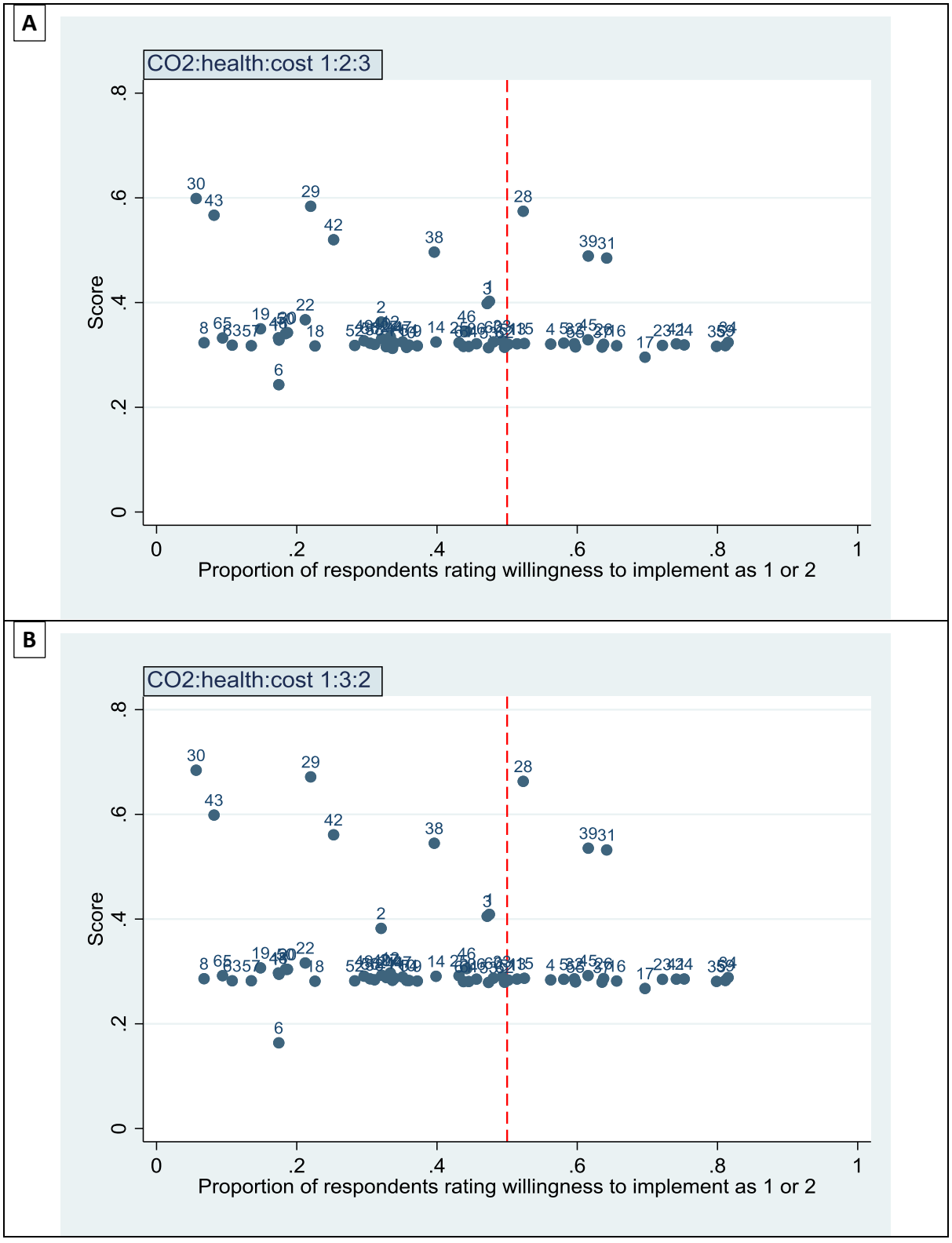
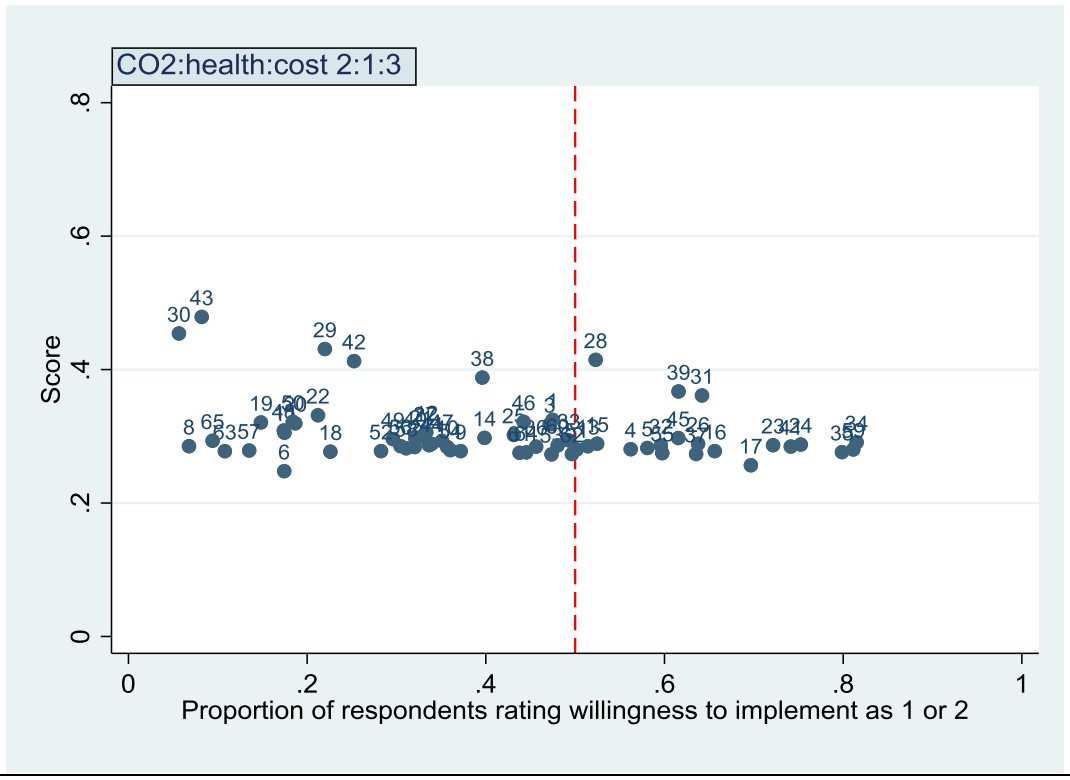


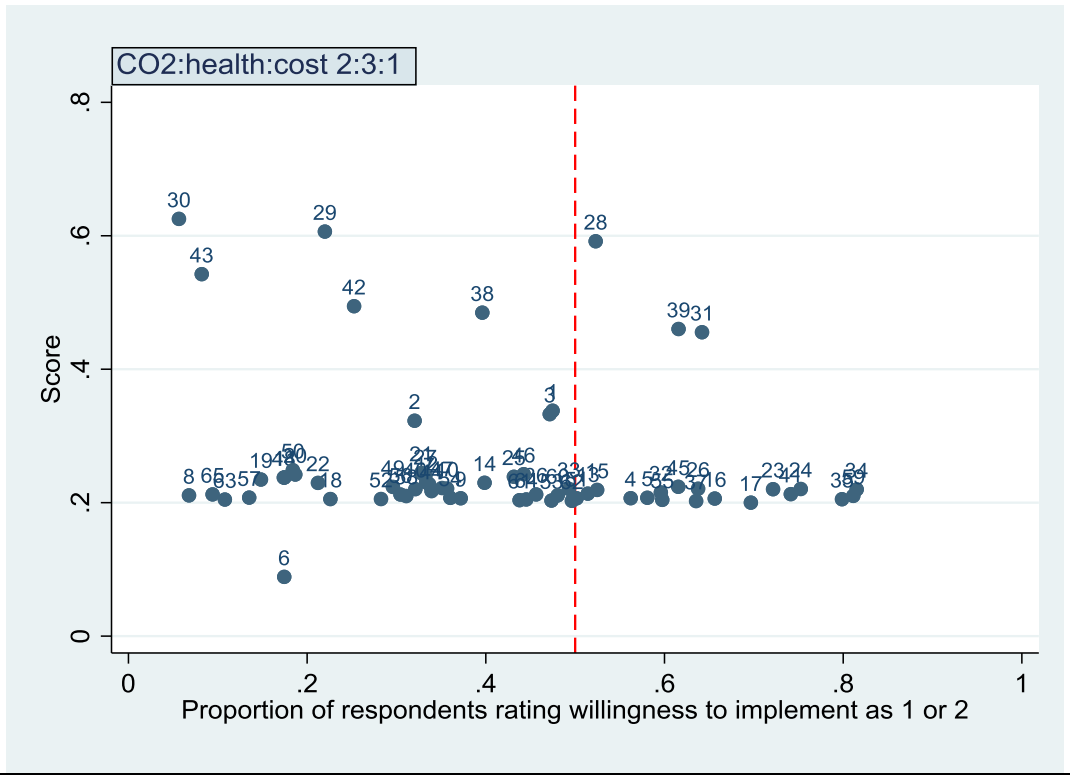
Figure 2. Relationship between the equal-weighting multi-criteria score and the proportion of respondents indicating that they were willing (Likert score 2) or very willing (Likert score 1) to implement the action. Actions are numbered as in Table 1. (Note that responses where the action was already implemented or not applicable are excluded from this analysis, which gives some differences in scores by comparison with Figure 1.2.)

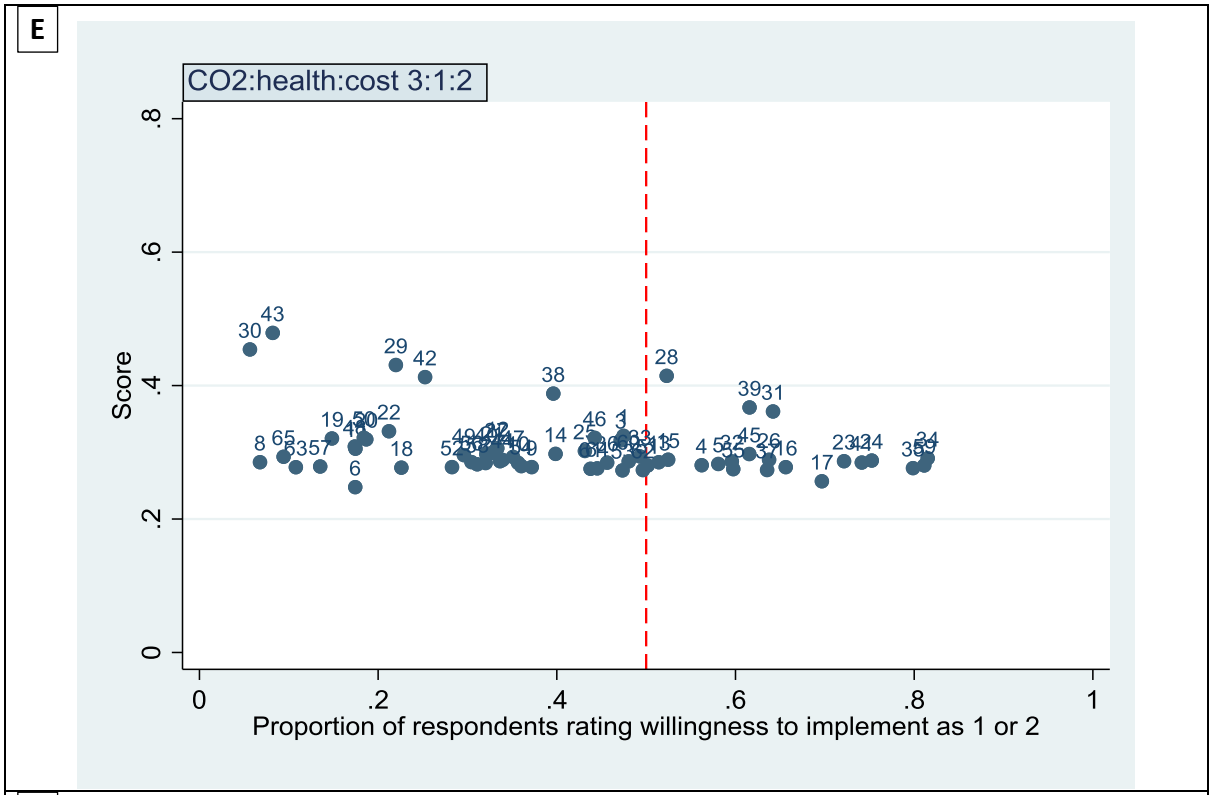

A
CO2:health:cost 1:2:3
Score
0
.2
.4
.6
.8
0
.2
.4
.6
.8
1
Proportion of respondents rating willingness to implement as 1 or 2
B
CO2:health:cost 1:3:2
Score
0
.2
.4
.6
.8
0
.2
.4
.6
.8
1
Proportion of respondents rating willingness to implement as 1 or 2

C


CO2:health:cost 2:1:3
Score
0
.2
.4
.6
.8
0
.2
.4
.6
.8
1
Proportion of respondents rating willingness to implement as 1 or 2

D


CO2:health:cost 2:3:1
Score
0
.2
.4
.6
.8
0
.2
.4
.6
.8
1
Proportion of respondents rating willingness to implement as 1 or 2



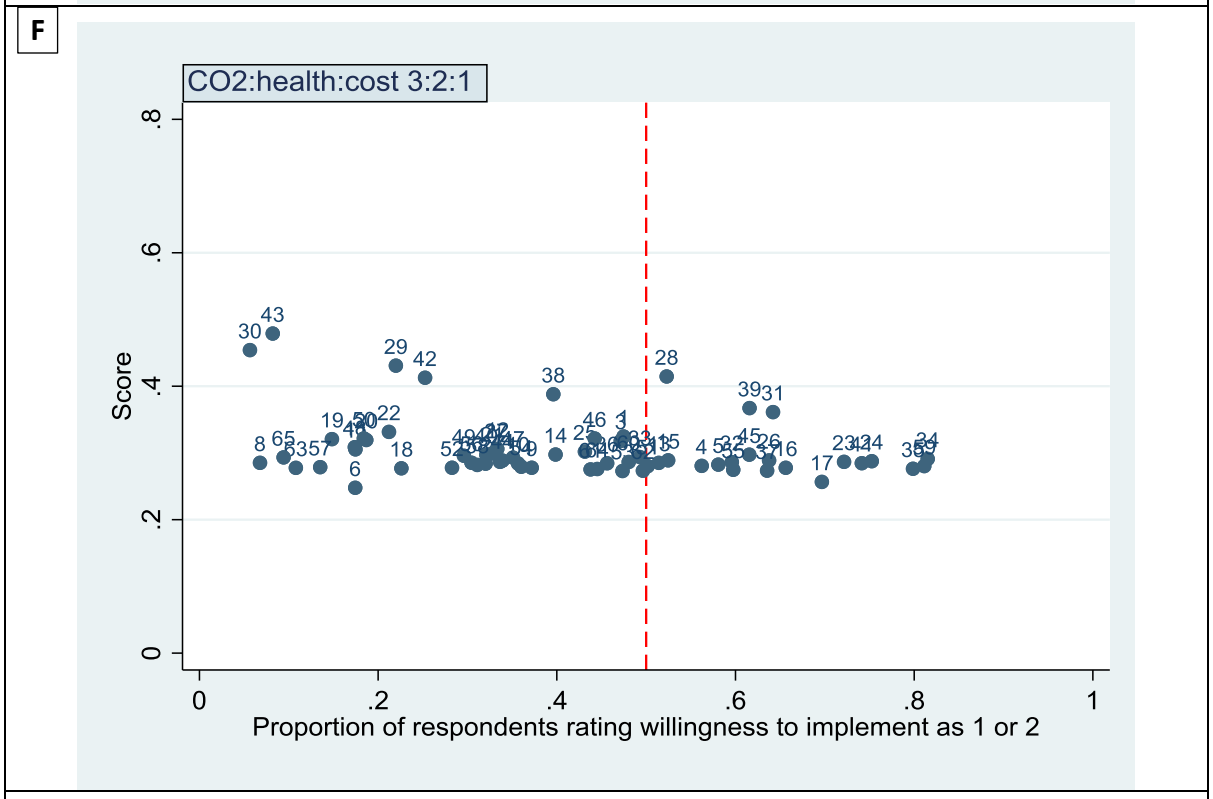
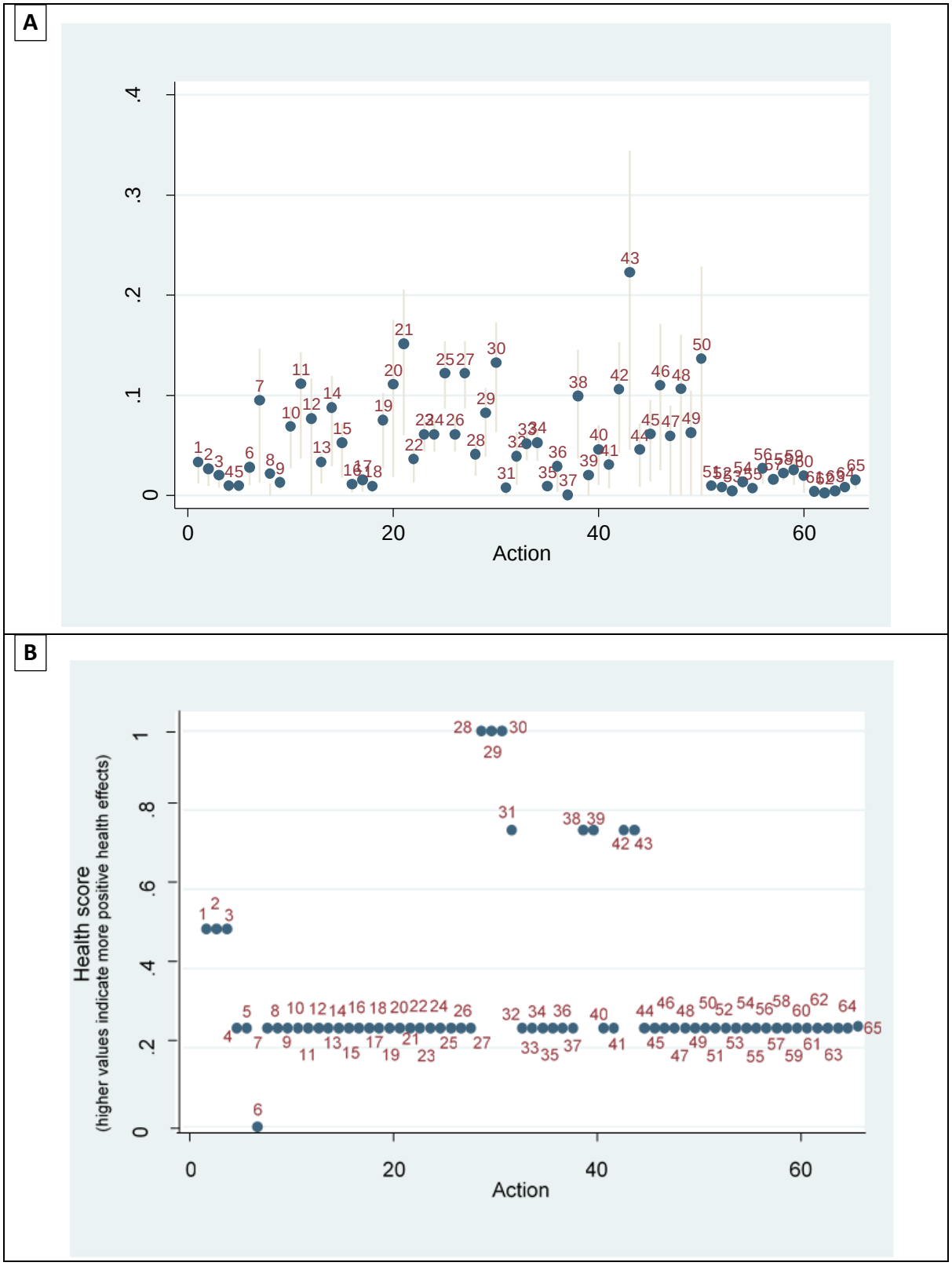
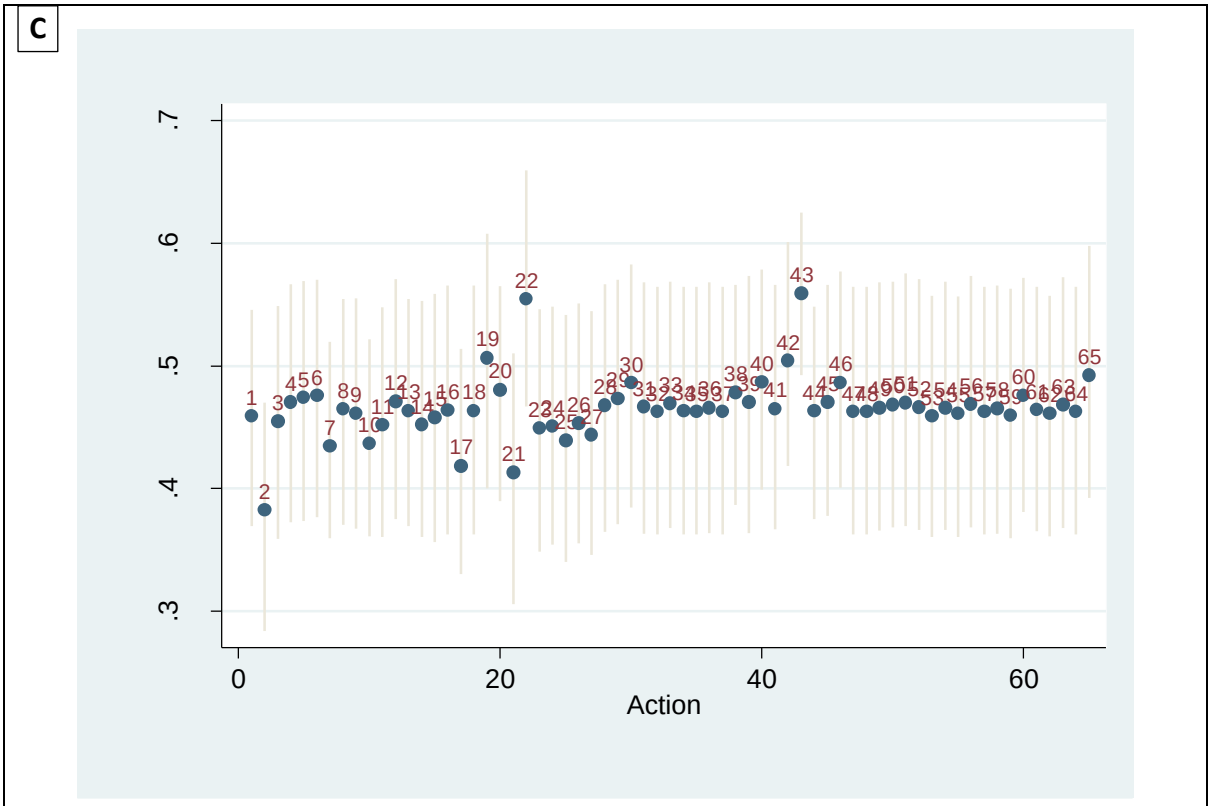


Figure 3. Variants of Figure 2 on the relationship between the multi-criteria score and the proportion of respondents indicating that they were willing (Likert score 2) or very willing (Likert score 1) to implement the action. The relative weights for CO_2 saving, health impact and cost saving are indicated at top left of each plot.

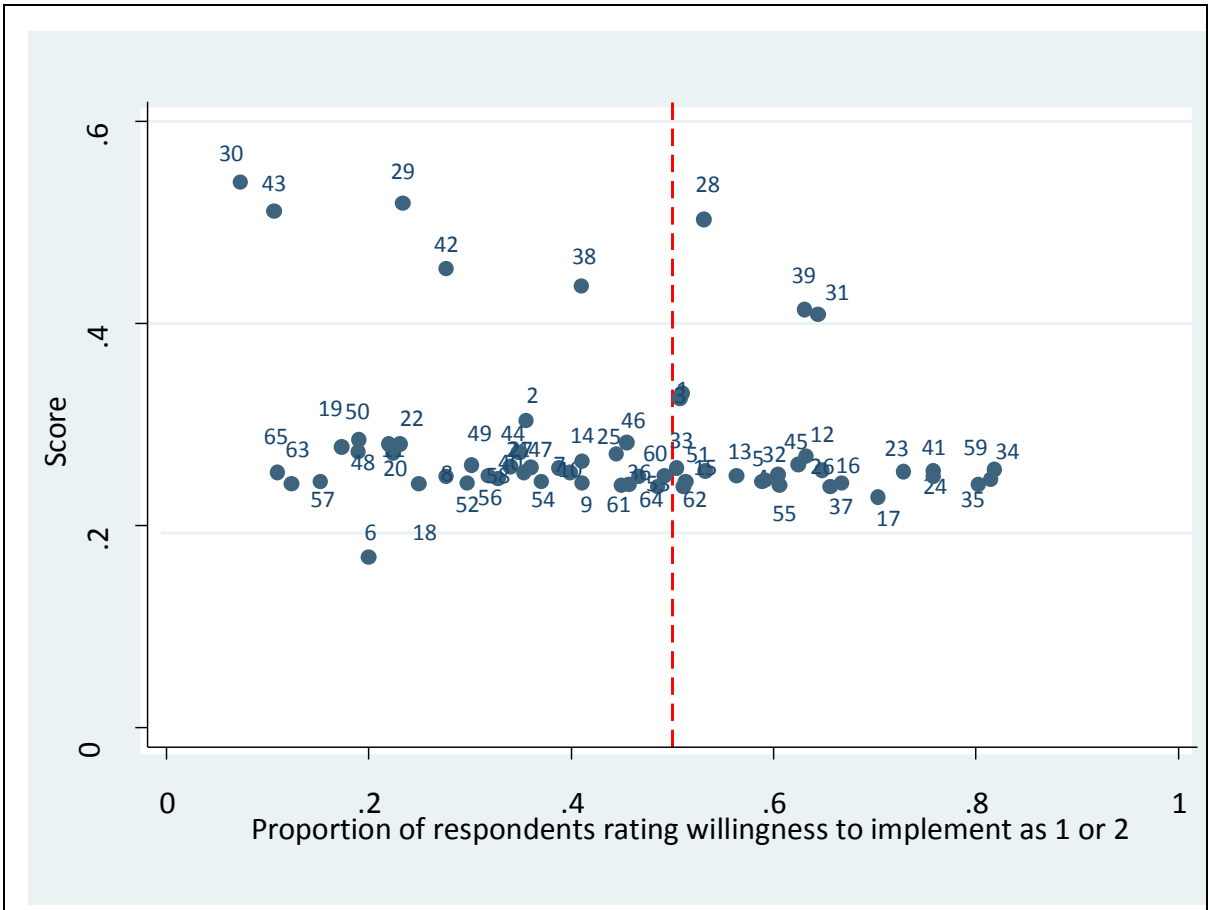
Appendix


A
0
.1
.2
.3
.4
0
20
40
60
Action
B
Health score
(higher values indicate more positive health effects)
0
.2
.4
.6
.8
1
0
20
40
60
Action



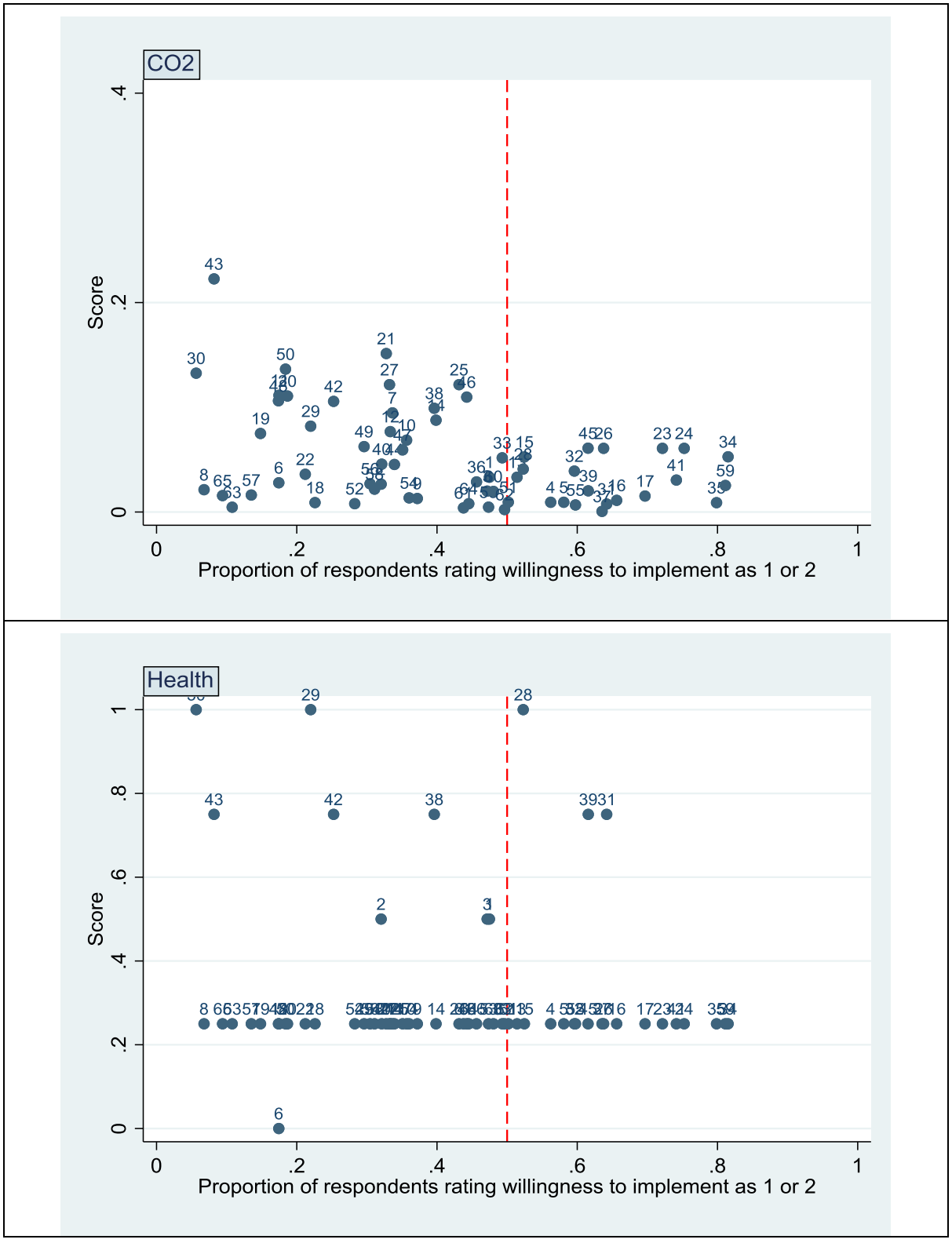
Appendix Figure 1. Distribution of scores (mean and inter-quartile range (IQR)) for each of the three criteria : [A] CO_2e saving, [B] health and [cost]. CO_2e savings are scaled relative to the target reduction (50% of household emissions), costs with respect to the range of values from implementing all actions (a range that includes cost savings for relevant actions), and health with respect to categories. For health, a score of zero indicates a small adverse health impact, 0.25 no health impact, and scores of 0.5, 0.75 and 1 as the +, ++ and +++ categories of positive benefits. Health scores are shown as point estimates only as IQR ranges are typically zero.

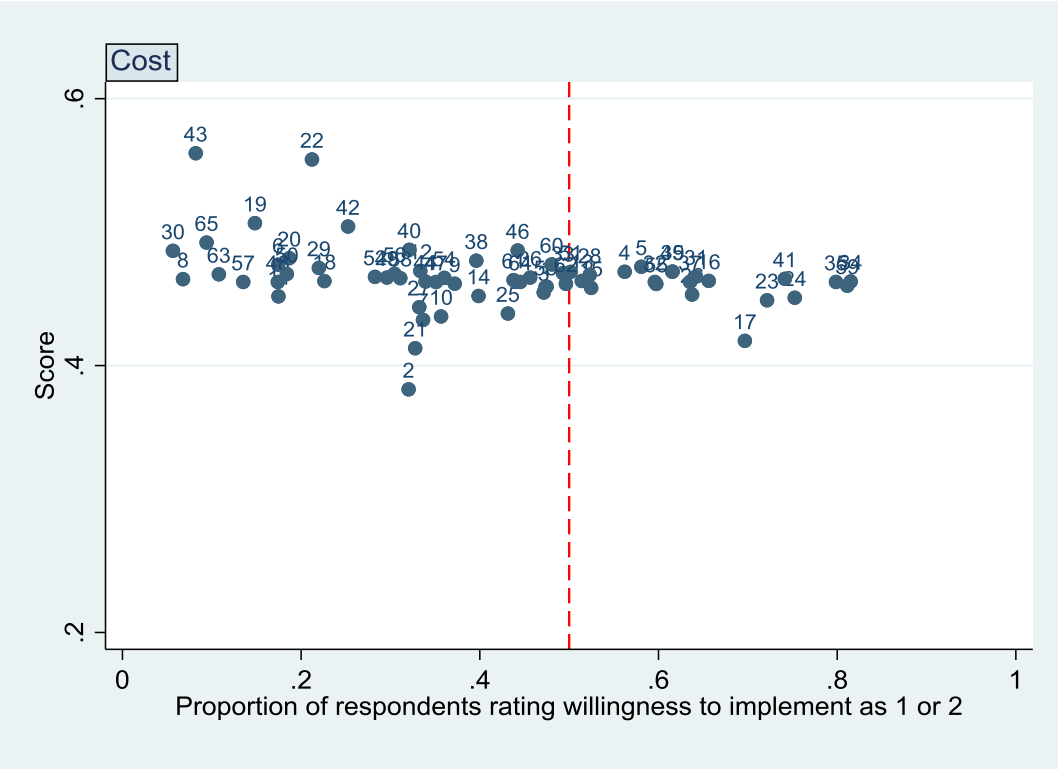
A
B
C
D
E



Appendix Figure 2. Relationship between the equal-weighting multi-criteria score and the proportion of respondents indicating that they were willing (Likert score 2) or very willing (Likert score 1) to implement the action or had already implemented it. Actions are numbered as in Table 1.

This is an alternative to Figure 2 of the main text which excludes responses from households where the intervention in question was already implemented.


CO2
Score
0
.2
.4
0
.2
.4
.6
.8
1
Proportion of respondents rating willingness to implement as 1 or 2
Health
Score
0
.2
.4
.6
.8
1
0
.2
.4
.6
.8
1
Proportion of respondents rating willingness to implement as 1 or 2



Appendix Figure 3. Relationship between the individual criteria (CO2e, health impact, cost saving) and the proportion of respondents indicating that they were willing (Likert score 2) or very willing (Likert score 1) to implement the action.