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Challenges in Achieving 1.5-Degree Lifestyle Mitigation Options—Insights from a Citizen-Participatory Household Experiment in Japan

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Abstract: Recent studies have highlighted the significant role of lifestyle changes in achieving climate change targets. However, implementing substantial changes in people's lifestyles is challenging due to the varying availability of goods and services and the influence of the surrounding environment. To address this challenge and promote low-carbon and decarbonised lifestyles on a societal scale, a two-week household experiment was conducted in four representative Japanese cities (Kyoto, Yokohama, Kitakyushu, and Kagoshima). The experiment was based on 65 carbon reduction/mitigation options proposed in previous studies. A total of 84 participants participated in the household experiments: 29 in Kyoto, 22 in Yokohama, 12 in Kitakyushu, and 21 in Kagoshima. Due to constraints imposed by the COVID-19 pandemic, implementation was monitored through a 'household experiment diary'. The household experiments examined the status of implementation of each option and assessed the potential for improvement over a short period. Furthermore, the study identified barriers, enabling contexts and proposed support measures for implementing household mitigation actions. This study also provided policy implications for co-creating decarbonised lifestyles.

Keywords: lifestyle; decarbonisation; carbon footprint (CFP); 1.5-degree; household; consumer behaviour; mitigation option

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1. Introduction

Global efforts to tackle climate change are expanding, deepening, and accelerating, as exemplified by the increasing political commitment by national and local governments to achieve net zero carbon emissions. Notably, recognising the necessity to change our ways of living has become a key element in addressing climate change. As stated in the Intergovernmental Panel on Climate Change (IPCC) 1.5-degree Special Report, "human behaviour and lifestyles are enabling conditions that enhance the feasibility of mitigation and adaptation options for 1.5 °C-consistent systems transitions" [1] (p. 19). The decarbonisation of lifestyles has gained further attention since the Working Group III Sixth Assessment Report highlighted the large untapped potential of demand-side mitigation measures to bring down global GHG emissions by 40–70% by 2050 compared to a baseline scenario [2]. As such, social and demand-side mitigation through behavioural change, alongside supply-side transitions, can play a crucial role in accelerating the large-scale socio-economic transformations necessary to limit the increase in global average temperature to 1.5 degrees above pre-industrial levels.

Despite the urgent need to accelerate the diffusion of decarbonised lifestyles, there is limited and fragmented knowledge and application of mitigation behaviours in practical settings [3,4]. Numerous studies have focused on individuals' norms and attitudes towards low-carbon behaviours in shaping lifestyle choices [5,6]. However, it has been observed that holding up pro-environmental values may not necessarily lead to sustainable lifestyles, as a value-action gap often arises due to situational or psychological constraints

in individuals' daily lives [7,8]. This emphasises the need for a deeper and more practical understanding of the factors that enable or hinder lifestyle changes to promote the diffusion of decarbonised lifestyles.

The Institute for Global Environmental Strategies (IGES), the research institute to which the authors are affiliated, conducted several pilot initiatives in the field of action research, contributing to the realisation of low-carbon lifestyles at the urban level as part of the 1.5-Degree Lifestyles project, a sustainable lifestyles and education programme under the 10-Year Framework of Programmes on Sustainable Consumption and Production (10YFP). As part of this effort, the 1.5-degree lifestyle report estimated carbon footprints (CFP) primarily based on physical consumption data to identify emission hotspots where reductions can be made, such as through shifts and substitutions between consumption modes and a decrease in amounts of physical consumption [9]. It was shown that focusing efforts to change lifestyles in relation to nutrition, housing, and mobility domains, especially targeting meat and dairy, fossil-fuel-based energy, car use and air travel, would yield the most benefits. As a result, approximately 50 low-carbon lifestyle options across four domains (food, housing, mobility, and consumer goods) were identified. The project team then embarked on practice-based experiments in households to co-create pathways for mitigation based on the application of low-carbon lifestyle options in households. The project team worked closely with local governments and citizens in six cities in five countries (Cape Town, Kyoto, New Delhi, Nonthaburi, São Paulo and Yokohama) to identify the carbon footprint of residents, organise workshops to discuss opportunities for future low-carbon lifestyles, pilot low-carbon behavioural options at the household level, and co-create future visions of decarbonised lifestyles that are relevant and responsive to local needs and conditions [10–15]. Based on the initial methodology and findings, similar workshops and household experiments were conducted in other cities in Japan, aiming to provide action-based inputs to city-level mitigation plans, create educational materials, and encourage collaboration between local governments, businesses, and citizens. Following these experiments, Watabe & Yamabe-Ledoux [16] conducted a qualitative analysis of the use of the carbon footprinting method during 1.5-degree lifestyle workshops to provide participants with a measurable and comparable figure reflecting the level of carbon emissions from their lifestyle, as well as to develop stakeholders' mitigation capacities and engage citizens in participatory policy-making processes.

Against this backdrop, this study provides a quantitative analysis based on the results of workshops and household experiments conducted in four cities in Japan: Kagoshima, Kitakyushu, Kyoto, and Yokohama, to promote the diffusion of decarbonised lifestyles. The research contents mainly consist of (1) providing an overview of participants' lifestyle carbon footprint in six domains: housing, mobility, food, consumer goods, leisure and others (services, etc.), (2) examining the current status of implementing each carbon mitigation option and exploring the potential for short-term and long-term improvements, (3) identifying barriers, enabling factors, and proposing support measures for implementing carbon reduction measures in households, and (4) presenting policy implications related to the co-creation of decarbonised lifestyles. These aspects help address the following research questions: "What is the current status of lifestyle carbon footprint and the proposed carbon mitigation options?", "What are the barriers, enablers and necessary support measures for the widespread adoption of low-carbon lifestyles?", and "How can these insights contribute to the development of supportive environments to accelerate the transition to a decarbonised society?"

2. Literature Review

The transition to a decarbonised society is a complex and multifaceted process going far beyond the simple adaptation of an existing system brought about by the assimilation of new technologies and practices. This transition is expected to undergo several phases, from its emergence in peripheral niches to its adaptation and diffusion in wider communities before stabilisation [2]. Niche low-carbon communities have been multiplying and offer

valuable lessons and potential models for developing net zero communities [17]. Nevertheless, the diffusion of decarbonised ways of living has been too slow, evidencing the complexity of modifying people's lifestyles. While some lifestyle aspects are voluntary, others are strongly influenced by the availability and accessibility of goods and services, the surrounding infrastructure, and community conditions. Additionally, consumers in modern societies are often locked into larger social trends of long working hours and mass consumption lifestyles.

The diffusion rates of sustainable lifestyles largely depend on various drivers and supporting measures to overcome many barriers [4]. Furthermore, the public's acceptability of the transition to sustainable lifestyles is influenced by the social mandate for change built through public engagement to discuss and develop recommendations for policymakers [2]. While it is desirable to accelerate the decarbonisation of our society, there is the risk that short-cutting crucial experimental and social learnings in the formative phase of the transition may lead to lock-in situations with potentially undesirable effects [2,18].

Meanwhile, socio-economic tipping points and amplifiers may present 'sensitive intervention points' to speed up low-carbon transitions [19]. The community and local levels serve as primary leverage points where individuals reside, commute, and consume various goods and services [20]. Many barriers can be found and shaped at the micro- and local levels. This is also where social structures can best structure stakeholders' responsibilities and enable opportunities for change [21]. From this perspective, the local level is crucial in delivering systemic changes towards decarbonisation. Nonetheless, past studies on locally driven carbon reduction initiatives have underscored the challenges of involving the public in community projects and maintaining long-term environmentally friendly actions [22].

This raises the question of the capability of different stakeholders in fostering and enabling decarbonised lifestyles. Particularly, it is essential to explore the role of local governmental bodies in involving citizens and other local stakeholders in envisioning and creating decarbonisation agendas through participatory approaches. Mont et al. demonstrates the importance of stakeholder engagement in social innovation processes in enabling and mainstreaming sustainable lifestyles [3]. Adopting a participatory approach to climate mitigation stems from the complexity of policy demands, limited enforceability of national policies in households, and anticipated disruptions to local industries [23]. Participative processes developing local mitigation scenario pathways can highlight gaps between theory and practice [24]. It is also instrumental in enhancing key stakeholders' understanding of the upcoming transition and encouraging equitable and legitimate solutions that are more likely to be adopted and effective at achieving policy goals than top-down approaches to policymaking [25].

Recent projects piloting and examining participatory processes to formulate sustainability plans offer valuable lessons. Axon [4] conducted focus group conversations to outline practical barriers and enablers at the community level to support the societal transformation towards sustainable lifestyles. The SPREAD Sustainable Lifestyles 2050 project in the EU in 2011 applied participative approaches to engage citizens in the development of 2050 mitigation scenarios based on various lifestyle patterns [26]. The project highlighted gaps between theory and practice, the need to apply research, and conduct pilot projects and socio-technical demonstrations to test and validate sustainable concepts and policy roadmaps [3]. It was also suggested that lifestyle-level scenario-making could empower early adopters of sustainable low-carbon lifestyles [24]. Urban Transition Labs were also highlighted as new local governance entities applying participatory processes in leading societal transitions [20]. Beyond the rare documentation on pilot initiatives to test mitigation solutions at the household level across domains, we note a lack of detailed analysis of the barriers and challenges experienced by individuals and their need for supporting measures to adopt low-carbon lifestyles. Specifically, we highlight that the crucial provision of locally adapted support for low-carbon societies benefits from an in-depth understanding of residents' lifestyle characteristics which can be gained from local participatory experiments.

While participatory methods in co-creating mitigation policies at the local level have been gaining attention, there is limited literature on a dual approach to policy planning combining a participatory process with the practical involvement of individuals to test, experiment and evaluate new sustainable behaviours. It is, however, essential to conduct pilot projects and socio-technical demonstrations to test and validate sustainable concepts and policy roadmaps. It is worth noting that co-creation approaches to policy planning towards decarbonisation have been most common in the housing domain, particularly in the heating and renewable energy sectors [23,25]. Elf et al. conducted an induction workshop where participants were given vouchers to purchase from a range of products categorised as sustainable [27]. The study's findings indicate that the provision of information and material support with a support network could facilitate the development of new capabilities, increase awareness of sustainability issues, foster a sense of belonging among participants, and provide a supportive environment, resulting in positive behavioural spillovers that were not reliant on external regulations. A study comparing scaling approaches to decarbonisation pilots suggests that relying solely on either top-down or bottom-up approaches is insufficient to achieve systemic change [28]. As such, lessons learnt from past experiences show that, to bring about comprehensive changes in socio-economic systems, policymakers need to formulate supportive policies that involve collaboration between government and non-governmental entities, emphasising local-level planning and citizen engagement.

By addressing these research gaps, this paper will contribute to the existing literature on the challenges faced in achieving 1.5-degree lifestyle mitigation options, specifically focusing on insights gained from citizen-participatory household experiments in Japan.

3. Materials and Methods

3.1. Scope of This Study

The main flow of activities for 1.5-degree lifestyle participatory initiatives is shown in Figure 1. First, an extensive analysis of lifestyle CFP at national and city levels was developed in the 1.5-Degree Lifestyle report [9]. Based on the 50 low-carbon lifestyle options presented in the initial report, the options menu was extended to 65 mitigation options across five lifestyle domains (housing, mobility, food, products, and leisure). The 65 mitigation options were compiled in an option catalogue (See Supplementary Materials), and each option was illustrated and associated with its CFP reduction potential.

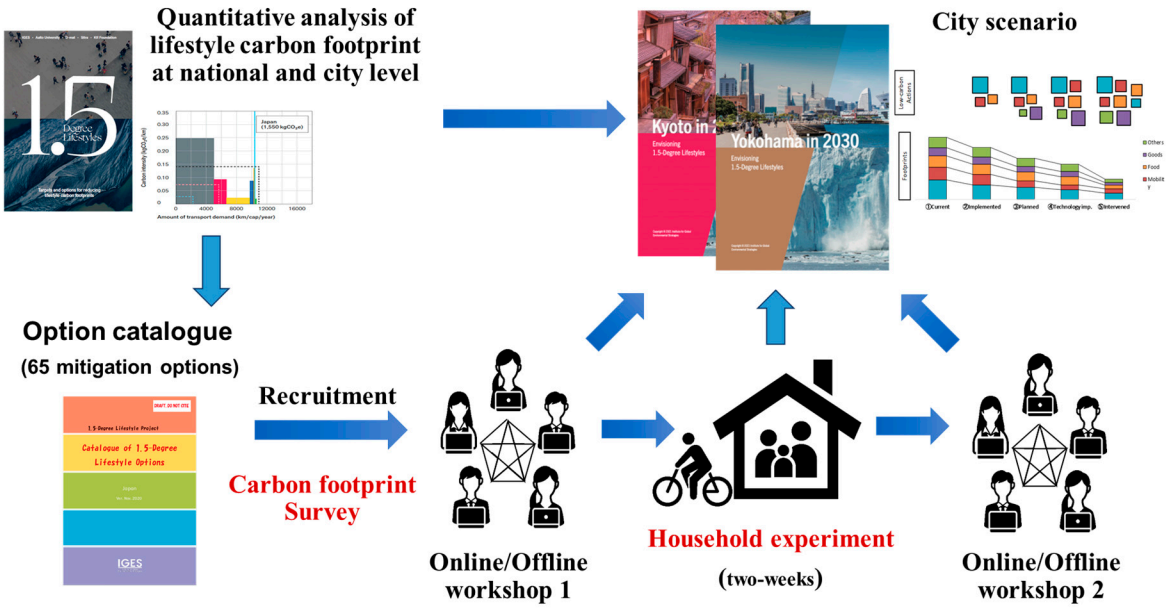

Figure 1. Workflow and scope of the 1.5-degree lifestyle project.

This study selected four cities in Japan as target cities: Kyoto, Yokohama, Kitakyushu, and Kagoshima. Two workshops and a two-week household experiment were conducted in each city in collaboration with local non-governmental organisations. Workshop participants of diverse ages, generations and professions were recruited. A volunteer-based sampling approach was adopted. Participants were actively recruited, and only those who expressed willingness and consent were included. While this method enhances the reliability of the gathered information by involving individuals who are interested in decarbonised lifestyles, it may lack universality. The recruitment of the workshop participants was supported by the city government and local NGOs. Before the workshops, a questionnaire was conducted to understand the participants' attributes, lifestyles, and carbon footprint. The lifestyle carbon footprint of each participant was estimated based on the results of the questionnaire.

The first workshop provided participants with an introductory presentation on climate change and the untapped potential of household consumption and lifestyles in mitigating greenhouse gas (GHG) emissions. Following an introduction of the 65 mitigation options, participants shared their future vision for their city. They identified carbon reduction options that aligned most with their long-term city vision. Participants then selected options to experiment at home as part of the household experiment. Following a two-week experiment, participants reconvened to discuss their challenges and supporting measures to adopt low-carbon lifestyles. Finally, a 2030 scenario for each city was co-created through a participatory consultation process, reflecting on outcomes from the discussions and citizens' experiences.

This study mainly analyses the carbon footprint survey and household experiments, which help understand the enablers and barriers in achieving 1.5-degree lifestyles and decarbonised societies.

3.2. CFP Survey of Each Participant

We used data from the baseline CFP questionnaire survey (paper-based and online) conducted in Kyoto, Kitakyushu and Kagoshima to analyse the relationship between CFP (housing and energy, mobility, food, products, leisure, other (services, etc.) and total) and attributes such as gender, age, family size, family composition, housing type, car ownership, residential area, employment status, household income, and awareness of food loss. The analysis of participants' CFP according to seven socio-demographic attributes revealed the characteristics of individuals with high CFP, such as their housing and employment situation.

Due to time constraints, CFP data could not be gathered from the Yokohama workshop participants. This was due to the difficulty of gathering participants to conduct household experiments within the limited timeframe and constraints imposed by the COVID-19 pandemic. As a result, the preliminary survey was simplified to reduce the burden on participants. Thus, Yokohama's estimations could not be included in the CFP analysis due to methodological differences in estimating participants' CFP.

The estimation of individual CFP provides a tangible and comparable indicator of the global impacts of participants' final consumption and lifestyles. This quantification method offers a valuable visualisation for carrying out citizen-participatory experiments and dialogues before engaging participants in formulating mitigation scenarios and concrete action proposals [16].

3.3. Household Experiment

The household experiment encouraged participants to try out carbon footprint reduction behaviours at home, identify barriers to behaviour change and develop recommendations for stakeholders, including governments and businesses, to work together.

Initial planning for the experiment included visits to households before and after implementing actions to advise and interview participants. However, constraints due to the COVID-19 pandemic prevented home visits from being carried out. A 'Recording Sheet'

(household experiment diary) was distributed to participants during the first workshop as an alternative monitoring measure. Participants could record their experience daily on the sheet to report on the result at the end of the experiment. Additional support and follow-up recommendations were provided by email and telephone for unclear points.

The 'Recording Sheet' (household experiments diary) consisted of 'Preparation and Planning', 'Implementation' and 'Summary' sections.

- For the 'preparation and planning' part, participants were first asked to share information about the normal implementation of mitigation options in their households before the start of the household experiment. They were then asked to select the reduction behaviours they planned to implement during the two-week experiment. Participants were also invited to describe preparations before the experiment (e.g., finding a shop to buy vegan or vegetarian food and discussing mitigation options with their families).
- For the 'implementation' part, participants were allowed to record the extent to which they implemented the 65 decarbonisation behaviours (e.g., 100%, 75%, 50%, 25%, 0%, etc.) daily over two weeks.
- For the 'summary' part, participants self-assessed the experiment according to the mitigation behaviours they had implemented. They could also provide general comments on any difficulties or obstacles they faced when implementing each decarbonisation behaviour and suggestions on supporting mechanisms and infrastructure to facilitate the wider implementation of 1.5-degree lifestyles.

During the final workshop, participants shared their experience implementing mitigation options at home and reflected on other participants' experiences. This discussion provided a concrete basis for participants to share ideas on how to implement and diffuse 1.5-degree lifestyles in their city, formulate additional suggestions for supporting measures, and initiate collective actions with key stakeholders towards the transition to a low-carbon society.

The results of the household experiments examined the implementation status of each mitigation option and the potential for improvement in a short period, as well as identifying barriers, 'enabling contexts' and expected support measures. Responses from participants provided essential information to categorise mitigation options systematically and showed evidence of differing levels of implementation based on their practices.

In the first round of household experiments in Kyoto and Yokohama, 65 options were included, while in the second round in Kitakyushu and Kagoshima, the experiments were limited to 41 options (indicated by the shorter bars in Figures 2 and 3). The reasons for this limitation were the large number of options that put a burden on participants, as well as the inclusion of infeasible options to implement within the short two-week period, such as "2. Live Close to Working Place", "7. Compact City", "41. Zero Energy House", and options dependent on specific timing, such as "13. Long Holidays in Japan" and "30. Heating by Air Conditioner". This decreased the number of respondents and hindered the comparative analysis between the four cities. However, it should be noted that these excluded options primarily consisted of options that were impractical to implement within the two-week household experiment. Therefore, the impacts of these options on the overall implementation rates and on the implementation status of options within the two weeks are limited.

4. Results and Discussion

4.1. Respondent Attributes and CFP Value

Table 1 summarises participants' characteristics, including "Gender", "Age", "Family size", "Family composition", "Type of housing", "Ownership of a private car", "Residential area", "Employment status", "Household income", and "Awareness of food loss". The team collected primary data from 84 individuals, including 29 participants in Kyoto, 22 in Yokohama, 12 in Kitakyushu, and 21 in Kagoshima. The age of participants ranges from 20 to over 80.

Table 1. Participants' socio-demographic attributes (n = 87).

		Total	Kyoto	Yokohama	Kagoshima	Kitakyushu	Percentage
	(n)	87	30	22	21	14	100%
Gender	Male	33	12	4	7	10	38%
	Female	52	18	18	13	3	60%
	No answer	2	–	–	1	1	2%
Age	<29	7	–	2	5	–	8%
	30–39	12	–	3	5	4	14%
	40–49	24	9	7	6	2	28%
	50–59	8	2	3	1	2	9%
	60–69	17	8	1	3	5	20%
	70–79	11	8	2	–	1	13%
	≥80	3	1	1	1	–	3%
	No answer	5	2	3	–	–	6%
Family size	1	16	3	3	9	1	18%
	2	31	13	5	6	7	36%
	3	16	5	5	3	3	18%
	4	15	5	6	2	2	17%
	5	4	3	–	–	1	5%
	6	0	–	–	–	–	0%
	7	2	1	–	1	–	2%
	No answer	3	–	3	–	–	3%
Family composition	Single	16	3	3	8	2	18%
	Couple	28	13	4	6	5	32%
	Family with children	18	7	8	2	1	21%
	Three-generation family	7	2	3	–	2	8%
	Others	15	5	1	5	4	17%
	No answer	3	–	3	–	–	3%
Type of housing	Self-owned detached house	39	21	5	6	7	45%
	Self-owned condominium	8	2	4	2	–	9%
	Rental detached house	5	2	–	2	1	6%
	Rental apartment/condominium	24	3	10	7	4	28%
	Others	6	2	–	3	1	7%
	No answer	5	–	3	1	1	6%
Ownership of a private car	Self-owned	53	20	8	13	12	61%
	Not owned	28	10	11	5	2	32%
	Others	6	–	3	3	–	7%

Table 1. *Cont.*

		Total	Kyoto	Yokohama	Kagoshima	Kitakyushu	Percentage
Residing area	Urban	39	22	–	11	6	45%
	Suburban	23	8	–	7	8	26%
	Others	3	–	–	3	–	3%
Employment status	Part-time 1 person	9	2	–	5	2	10%
	Full-time 1 person; Part-time 1 person	16	9	–	4	3	18%
	Full-time 1 person	13	5	–	5	3	15%
	Full-time 2 or more people	10	3	–	2	5	11%
	Others	7	3	–	4	–	8%
	Not employed	10	8	–	1	1	11%
Household income (million JPY)	<2.9	3	2	1	–	–	3%
	3.0~5.9	16	10	6	–	–	18%
	6.0~7.9	11	4	7	–	–	13%
	8.0~9.9	6	4	2	–	–	7%
	≥10	5	4	1	–	–	6%
	No answer	11	6	5	–	–	13%
Awareness of food waste	Concerned	45	21	–	15	9	52%
	Average	19	9	–	6	4	22%
	Not concerned	1	–	–	–	1	1%

This sample of participants does not aim to reflect the general population's willingness and readiness to adopt low-carbon lifestyles, nor does it aim to provide a representative sample of the population's different geographic and socio-demographic characteristics. Due to the limited sample sizes in each city and the low representativity of the surveyed participants, notable patterns in participants' characteristics across the four cities could not be observed in the data analysis. Additionally, the study acknowledges that the self-appointed participants are comparatively more aware, motivated and engaged in climate mitigation actions than the general public and can thus be seen as a niche group in the global transition to 1.5-degree lifestyles.

Nevertheless, considering socio-demographic influences can provide useful insights to identify emissions hotspots when designing and implementing decarbonisation measures. Age, income, and gender composition were identified as key factors affecting household energy consumption patterns by previous studies [29]. Notably, it was found that households' carbon footprint tends to peak when their residents are in their 50s in Japan [30]. Recent studies focusing on the correlation between consumption patterns and time allocation with household income showed that consumption outside of the household, such as eating out, transport and entertainment, increases linearly with income, while the tendency of lower-income families to spend more time at home and rely on inefficient technologies results in disproportionately high emissions at home (energy supply and food consumption at home) [29].

Individuals' readiness to adopt low-carbon behaviours was also shown to be influenced by socio-demographic characteristics. Past studies evidenced that individuals with advanced low-carbon behaviours and intentions were more likely to be employed, older, have spare money and time, and be female [31]. The survey also included participants' characteristics on house ownership as a critical indicator to measure the ability of participants to adopt mitigation options in the housing domains due to potential constraints to

modify aspects of household infrastructure for renters compared to homeowners. While it may be noted that renters have a greater ability to choose their accommodation based on existing low-carbon infrastructure, previous studies evidenced that homeowners were more likely to adopt advanced low-carbon behaviours [31].

The "Awareness of food waste" was self-reported by participants to reflect more responsible consumption patterns and their level of awareness of overall socio-environmental issues as an essential indicator to predict their intentions to adopt low-carbon behaviours. Overall, CFP estimations offer an initial overview of the various infrastructural and socio-cultural barriers and potential incentives in transitioning to sustainable and low-carbon lifestyles in several cities.

4.2. CFP

This section aimed to clarify the status of participants' CFP and investigate the characteristics of individuals with a comparatively higher/lower CFP. The mean CFP value (M), along with the number of participants (*n*) and standard deviation (SD) of CFP of each domain ("Housing", "Mobility", "Food", "Products", "Leisure", "Others (services, etc.)", and "Total") in Kyoto, Kagoshima and Kitakyushu, was summarised in Table 2, considering socio-demographic attributes such as "Gender", "Age", "Family size", "Family composition", "Type of housing", "Ownership of a private car", "Residential area", "Employment status", "Household income", and "Awareness of food loss". The data bar displayed the mean value for each attribute. Chi-squared tests examined the relationship and significance of differences between participants' CFP domains and socio-demographic attributes (Table 3). Categories with extremely low frequencies, such as "prefer not to answer" or "other", were excluded from the analysis. Furthermore, to ensure the reliability of the chi-squared tests, some attributes, except for gender, were re-categorised to reduce the number of categories. We calculated the average CFP for each domain. We divided the participants into two groups: the "high emissions group" with a CFP score above the mean and the "low emissions group" with a score below the mean.

Table 2. Cross-tabulation of participants' lifestyle CFP ($kgCO_2e$/person/year) for each domain and their socio-demographic attributes.

		Housing			**Mobility**		**Food**		**Products**		**Leisure**		**Others (Services, etc.)**		**Total**	
Attribute		**n**	**M**	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**
	Total	65	2044	1272	1905	2213	1148	159	1146	180	783	109	571	119	7630	2477
Gender	Male	29	2039	1591	2436	2969	1172	172	1185	186	804	113	605	126	8245	3225
	Female	34	2119	988	1440	1232	1133	151	1120	168	763	105	538	107	7116	1535
	No answer	2	1835	491	2115	1031	1064	64	1008	284	812	25	614	0	7448	1894
Age	<29	5	3239	3522	2153	2963	1252	251	1037	379	840	103	584	166	9104	4155
	30–39	9	1772	476	2741	3107	1092	161	1181	126	797	106	603	173	8205	3313
	40–49	17	1831	746	1769	1730	1096	132	1108	168	760	72	552	108	7115	1696
	50–59	5	2627	782	1433	1730	1165	122	1090	160	680	149	554	173	7547	1520
	60–69	16	2214	917	1724	1415	1170	184	1194	154	786	138	548	78	7635	1349
	70–79	9	1887	1418	934	690	1182	133	1173	154	798	76	580	101	6555	2010
	≥80	2	1606	166	1072	859	1240	73	1077	0	842	84	614	0	6450	536
	No answer	2	1414	30	6523	6760	1126	44	1278	284	875	73	690	107	11905	7238
Family size	1	13	2805	2273	1359	940	1159	182	1087	201	790	126	556	158	7762	2306
	2	26	2119	941	1438	1541	1129	149	1141	160	774	119	544	115	7145	1661
	3	11	1667	636	2161	1645	1163	164	1107	184	801	103	559	77	7458	1831
	4	9	1641	527	2507	3474	1139	130	1210	142	772	97	620	99	7900	3647
	5	4	1567	729	3390	4745	1115	208	1177	195	773	79	652	76	8674	4692
	6	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	7	2	1950	164	4452	4128	1357	172	1447	239	811	13	690	107	10706	4823
	No answer	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Table 2. *Cont.*

Attribute		Housing			Mobility		Food		Products		Leisure		Others (Services, etc.)		Total	
		n	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Family composition	Single	13	2810	2259	1943	1951	1185	198	1134	247	806	124	544	182	8429	2856
	Couple	24	2100	975	1389	1557	1111	102	1149	164	756	96	557	108	7062	1699
	Family with children	10	1432	593	2681	3017	1072	105	1137	169	760	72	604	106	7696	3193
	Three-generation family	4	2011	180	1256	1220	1288	144	1210	146	823	41	614	0	7201	1146
	Others	14	1825	628	2386	2887	1191	204	1139	174	812	141	582	88	7935	2967
Type of housing	Self-owned detached house	34	2038	1021	1757	2066	1178	155	1181	149	788	121	562	104	7507	2258
	Self-owned condominium	4	1549	290	2448	1781	1154	101	1143	95	789	59	614	124	7698	2054
	Rental detached house	5	1920	438	2217	1697	994	86	1090	269	721	93	553	83	7495	1685
	Rental apartment/condominium	14	2445	2131	1927	2341	1188	185	1120	237	822	87	560	175	8068	2979
	Others	6	2096	1019	737	577	1017	98	1031	151	702	98	589	62	6172	963
	No answer	2	1471	25	5917	5994	1128	85	1212	190	798	21	690	107	11215	6203
Ownership of a private car	Self-owned	45	2078	842	1999	2423	1136	156	1154	167	769	117	561	117	7701	2481
	Not owned	17	2092	2121	1409	1109	1163	162	1104	193	819	88	578	126	7169	2152
	Others	3	1919	379	3305	3545	1246	209	1257	311	780	41	665	88	9171	4284
Residing area	Urban	39	2165	1472	1894	2384	1177	156	1151	189	801	110	583	126	7773	2690
	Suburban	23	1912	961	1621	1626	1097	142	1123	148	757	107	537	100	7051	1661
	Others	3	2136	68	4231	3259	1164	280	1257	311	747	69	665	88	10199	3782
Employment status	Part-time 1 person	9	1775	886	2266	1565	1160	225	1099	277	780	150	580	166	7660	1868
	Full-time 1 person; Part-time 1 person	16	2045	649	1166	1140	1117	156	1139	146	745	109	576	104	6788	1244
	Full-time 1 person	13	1929	563	1849	1450	1160	203	1164	127	814	128	536	116	7466	1331
	Full-time 2 or more people	10	1941	821	3917	4020	1131	63	1137	223	791	94	554	147	9470	4028
	Others	7	2332	1311	1955	2456	1206	178	1202	215	768	85	614	88	8077	3205
	Unemployed	10	2533	2728	790	718	1150	98	1144	145	807	59	584	96	7007	2618
Household income (million JPY)	<3	2	1669	642	2308	1272	1079	127	977	142	818	50	538	107	7390	1488
	3~6	10	1994	1626	947	665	1150	114	1184	106	799	73	523	78	6595	2027
	6~8	4	1659	561	769	549	1160	104	1278	0	733	120	538	88	6137	892
	8~10	4	2196	532	1728	627	1162	58	1295	34	753	117	538	152	7672	741
	≥10	4	1536	716	3725	5251	1084	138	1143	226	781	124	690	88	8957	5443
	No answer	6	1799	542	1832	1838	1198	138	1132	242	787	36	639	62	7387	1884
Awareness of food waste	Concerned	45	2172	1478	1900	2161	1116	150	1128	172	780	107	558	108	7659	2477
	Average	19	1876	574	1483	1424	1229	158	1176	199	787	117	590	136	7140	1738
	Not concerned	1	1454	–	10155	–	1067	–	1346	–	813	–	766	–	15601	–

M: mean, SD: standard deviation.

Table 3. Chi-squared test results for the relationship between participants' domain-related CFP and socio-demographic attributes.

Domain	CFP		Gender		*p*-Value	Age		*p*-Value	Family Size		*p*-Value	Family Composition		*p*-Value	Type of Housing		*p*-Value
			Male	Female	χ	<50	≥50	χ	≤2	≥3	χ	Single/Couple	Family with Children/Three-Generation Family	χ	Self-Owned	Rental	χ
Housing	Low emissions group	n	15 51.7%	16 47.1%	0.712	16 51.6%	14 43.8%	0.532	16 41.0%	16 61.5%	0.105	15 41.7%	10 66.7%	0.104	18 47.4%	9 47.4%	1.000
	High emissions group	n	14 48.3%	18 52.9%		15 48.4%	18 56.3%		23 59.0%	10 38.5%		21 58.3%	5 33.3%		20 52.6%	10 52.6%	
Mobility	Low emissions group	n	18 62.1%	24 70.6%	0.475	18 58.1%	24 75.0%	0.154	30 76.9%	13 50.0%	0.025 **	27 75.0%	8 53.3%	0.129	24 63.2%	12 63.2%	1.000
	High emissions group	n	11 37.9%	10 29.4%		13 41.9%	8 25.0%		9 23.1%	13 50.0%		9 25.0%	7 46.7%		14 36.8%	7 36.8%	
Food	Low emissions group	n	16 55.2%	22 64.7%	0.441	23 74.2%	16 50.0%	0.048 **	26 66.7%	14 53.8%	0.298	25 69.4%	9 60.0%	0.514	19 50.0%	14 73.7%	0.088 *
	High emissions group	n	13 44.8%	12 35.3%		8 25.8%	16 50.0%		13 33.3%	12 46.2%		11 30.6%	6 40.0%		19 50.0%	5 26.3%	
Products	Low emissions group	n	16 55.2%	18 52.9%	0.859	18 58.1%	16 50.0%	0.521	23 59.0%	12 46.2%	0.310	20 55.6%	6 40.0%	0.311	17 44.7%	12 63.2%	0.190
	High emissions group	n	13 44.8%	16 47.1%		13 41.9%	16 50.0%		16 41.0%	14 53.8%		16 44.4%	9 60.0%		21 55.3%	7 36.8%	
Leisure	Low emissions group	n	13 44.8%	16 47.1%	0.859	14 45.2%	15 46.9%	0.891	18 46.2%	11 42.3%	0.760	17 47.2%	6 40.0%	0.637	16 42.1%	9 47.4%	0.706
	High emissions group	n	16 55.2%	18 52.9%		17 54.8%	17 53.1%		21 53.8%	15 57.7%		19 52.8%	9 60.0%		22 57.9%	10 52.6%	
Others (services, etc.)	Low emissions group	n	8 27.6%	15 44.1%	0.174	11 35.5%	12 37.5%	0.868	17 43.6%	6 23.1%	0.090 *	16 44.4%	3 20.0%	0.100	15 39.5%	7 36.8%	0.847
	High emissions group	n	21 72.4%	19 55.9%		20 64.5%	20 62.5%		22 56.4%	20 76.9%		20 55.6%	12 80.0%		23 60.5%	12 63.2%	
Total	Low emissions group	n	16 55.2%	23 67.6%	0.310	20 64.5%	19 59.4%	0.674	25 64.1%	15 57.7%	0.603	23 63.9%	10 66.7%	0.850	21 55.3%	12 63.2%	0.569
	High emissions group	n	13 44.8%	11 32.4%		11 35.5%	13 40.6%		14 35.9%	11 42.3%		13 36.1%	5 33.3%		17 44.7%	7 36.8%	

Table 3. *Cont.*

Domain	CFP		Ownership of a Private car		*p*-Value	Residing Area		*p*-Value	Employment Status		*p*-Value	Household Income		*p*-Value	Awareness of Food Waste		*p*-Value
			Not Owned	Owned	χ	Suburban	Urban	χ	Unemployed	Employed	χ	3~8 Million JPY	≥8 Million JPY	χ	Awareness	None in Particular	χ
Housing	Low emissions group	n	11 64.7%	19 42.2%	0.114	10 43.5%	21 53.8%	0.430	5 50.0%	24 50.0%	1.000	9 64.3%	4 50.0%	0.512	22 48.9%	9 47.4%	0.911
	High emissions group	n	6 35.3%	26 57.8%		13 56.5%	18 46.2%		5 50.0%	24 50.0%		5 35.7%	4 50.0%		23 51.1%	10 52.6%	
Mobility	Low emissions group	n	13 76.5%	28 62.2%	0.290	15 65.2%	27 69.2%	0.744	9 90.0%	28 58.3%	0.058 *	13 92.9%	5 62.5%	0.076 *	31 68.9%	12 63.2%	0.656
	High emissions group	n	4 23.5%	17 37.8%		8 34.8%	12 30.8%		1 10.0%	20 41.7%		1 7.1%	3 37.5%		14 31.1%	7 36.8%	
Food	Low emissions group	n	11 64.7%	28 62.2%	0.857	18 78.3%	20 51.3%	0.035 **	6 60.0%	32 66.7%	0.687	8 57.1%	4 50.0%	0.746	32 71.1%	7 36.8%	0.010 **
	High emissions group	n	6 35.3%	17 37.8%		5 21.7%	19 48.7%		4 40.0%	16 33.3%		6 42.9%	4 50.0%		13 28.9%	12 63.2%	
Products	Low emissions group	n	8 47.1%	25 55.6%	0.550	14 60.9%	19 48.7%	0.354	6 60.0%	25 52.1%	0.648	3 21.4%	3 37.5%	0.416	27 60.0%	8 42.1%	0.189
	High emissions group	n	9 52.9%	20 44.4%		9 39.1%	20 51.3%		4 40.0%	23 47.9%		11 78.6%	5 62.5%		18 40.0%	11 57.9%	
Leisure	Low emissions group	n	5 29.4%	23 51.1%	0.126	13 56.5%	14 35.9%	0.114	4 40.0%	22 45.8%	0.736	5 35.7%	4 50.0%	0.512	18 40.0%	11 57.9%	0.189
	High emissions group	n	12 70.6%	22 48.9%		10 43.5%	25 64.1%		6 60.0%	26 54.2%		9 64.3%	4 50.0%		27 60.0%	8 42.1%	
Others (services, etc.)	Low emissions group	n	5 29.4%	18 40.0%	0.441	10 43.5%	13 33.3%	0.424	3 30.0%	19 39.6%	0.570	8 57.1%	1 12.5%	0.040 **	19 42.2%	4 21.1%	0.107
	High emissions group	n	12 70.6%	27 60.0%		13 56.5%	26 66.7%		7 70.0%	29 60.4%		6 42.9%	7 87.5%		26 57.8%	15 78.9%	
Total	Low emissions group	n	12 70.6%	26 57.8%	0.356	15 65.2%	24 61.5%	0.772	7 70.0%	29 60.4%	0.570	11 78.6%	5 62.5%	0.416	27 60.0%	13 68.4%	0.525
	High emissions group	n	5 29.4%	19 42.2%		8 34.8%	15 38.5%		3 30.0%	19 39.6%		3 21.4%	3 37.5%		18 40.0%	6 31.6%	

χ: Chi-squared test, * $p < 0.10$, ** $p < 0.05$.

The participants' total CFP generation was 7630 kg CO_2e/person/year, comprising "Housing" (2044), "Mobility" (1905), "Food" (1148), "Products" (1146), "Leisure" (783), and "Others (services, etc.)" (571) (Table 2). This distribution closely aligns with the average CFP of the Japanese population, which is 7650 kg CO_2e/person/year, with contributions from "Housing" (2430), "Mobility" (1550), "Food" (1400), "Products" (1030), "Leisure" (580), and "Others (services, etc.)" (650) [21]. No significant differences were found between participants' total CFP generation and each socio-demographic attribute. However, when examining specific attributes, the analysis revealed some significant correlations and differences (Table 3).

In terms of age, the analysis was divided into two categories: 20s to 40s and 50s and above. There was a significant correlation between age groups, with individuals in their 20s to 40s having lower CFP than those aged 50 and older in the food category.

Regarding family size, a significant difference was observed in the "mobility" category, with households comprising two or fewer members showing a lower CFP tendency. A significant difference was found in the category of other (services, etc.), indicating that households with three or more members had a higher CFP tendency.

A significant correlation was found in the food category when considering housing type, with rental housing showing a lower CFP tendency than self-owned housing. Significant correlation and difference were observed in the food category regarding residing areas, indicating that suburban areas had a lower CFP tendency than urban areas.

Examining employment status, significant correlation and difference were found in the mobility category, with unemployed individuals having a lower CFP tendency. Analysing household income, a significant correlation was observed in the mobility category, showing that households with an income ranging from JPY 3 million to JPY 8 million had a lower CFP tendency. Additionally, a significant correlation was found in the category of other (services, etc.), indicating that households with an income of more than JPY 8 million had a higher CFP tendency.

Lastly, regarding awareness of food waste, a significant correlation was found in the food category, indicating that individuals who were conscious of food waste tended to have a lower CFP tendency in the food category.

4.3. Household Experiment

4.3.1. Current Implementation Status of the 65 Mitigation Options

At the first workshop, following an introduction to the mitigation options, participants were asked to report on their current level of implementation of each mitigation option. Respondents could choose between "1. Already implemented" (100%), "2. Mostly implemented" (75%), "3. Partially implemented" (50%), "4. Limited implementation" (25%), and "5. Not implemented" (0%) to indicate the extent to which each mitigation option had been adopted in their household over the year preceding the experiment. The result is shown in Figure 2.

The survey revealed that many participants were already actively implementing many mitigation options. Options with the highest levels of implementation ("Already implemented" and "Mostly implemented") were: "62. Longer Use and Using Up of Consumables", "33. Regulate Temperature by Clothing", and "48. Food Loss Reduction at Home". The "Products and services" domain showed the highest average implementation rate.

On the contrary, options showing the lowest implementation rate ("Limited implementation" and "Not implemented") were the following: "24. Plug-in Hybrid Vehicle with 100% Renewable Energy", "22. Electric Vehicle with 100% Renewable Energy", and "51. Shifting from Traditional Meat to Alternative Meat (Bean-based)". On average, the domains of "Mobility" and "Housing" showed the lowest implementation rate.

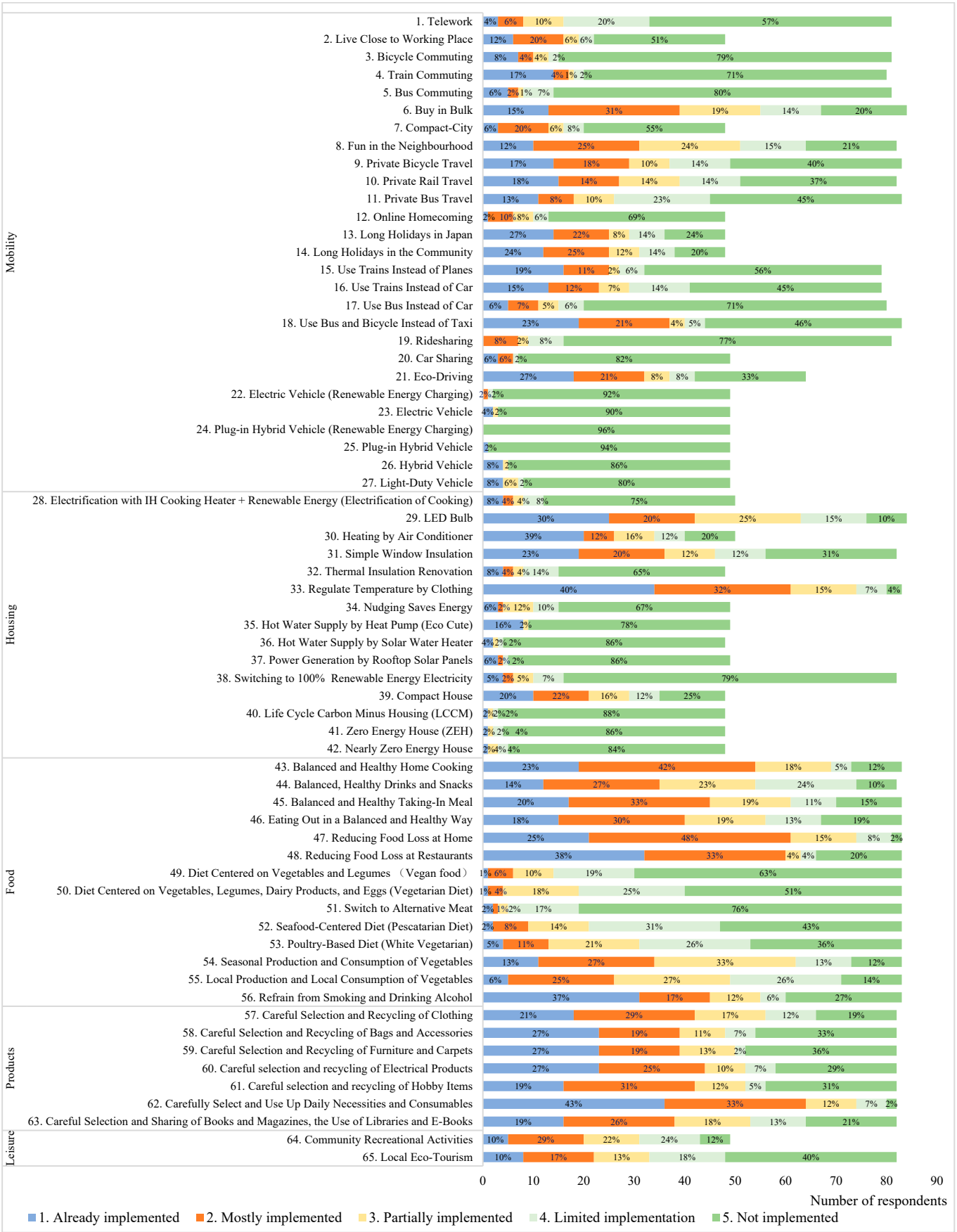

Figure 2. The current state of implementation of the 65 mitigation options.

This survey on the state of implementation of the 65 mitigation options before the household experiment provided an essential baseline on participants' consumption patterns and lifestyles to refer to following the experiment.

4.3.2. Challenges during the Household Experiment

Following the two-weeks household experiment, participants reported on the level of implementation of each mitigation option achieved at the end of the experiment. The levels of implementation could be indicated by five choices of responses: "1. Already implemented, so status quo maintained", "2. Already implemented to some extent, so status quo maintained", "3. Aiming to increase its implementation", "4. Not implemented, due to lack of opportunities during the experiment" and "5. Had no intention to implement it during the experiment". The responses are compiled in Figure 3.

The answer "1. Already implemented, so status quo maintained" and "2. Already implemented to some extent, so status quo maintained" designate the actions which were already implemented by participants before the start of the experiment. Response results mostly echo implemented options as reported in the survey (Figure 2), with mitigation options in the "Products" and "Food" being most commonly implemented. Options with the highest implementation rate were: "56. Refrain from Smoking and Drinking Alcohol", "62. Carefully Select and Use Up Daily Necessities and Consumables", and "48. Reducing Food Loss at Restaurants".

With the answer "3. Aimed to increase its implementation", participants selected options tested at home throughout the experiment. Answers to the survey revealed that participants were most proactive in testing mitigation options in the "Food" domain, such as "55. Local Production and Local Consumption of Vegetables", "44. Balanced, Healthy Drinks and Snacks", and "47. Reducing Food Loss at Home".

Options that participants could not or did not want to implement were categorised as: "4. Not implemented, due to lack of opportunities during the experiment" and "5. Had no intention to implement it during the experiment". Mitigation options which participants were unable to implement were most common in the "Mobility" and "Housing" domains. More specifically, options such as "24. Plug-in Hybrid Vehicle (Renewable Energy Charging)", "22. Electric Vehicle (Renewable Energy Charging)", and "40. Life Cycle Carbon Minus Housing (LCCM)" had the lowest implementation rate.

4.3.3. Cluster Analysis of 65 Mitigation Options

Based on the two indicators mentioned above (implementation status before and after the experiment in Sections 4.3.1 and 4.3.2), along with the potential mitigation value of each mitigation option, a hierarchical cluster analysis was conducted on all 65 mitigation options to explore their grouping patterns. The analysis utilised the complete linkage method and Euclidean distance measure, resulting in seven clusters. The dendrogram (in a circle) obtained from the analysis displayed the hierarchical structure of the clusters, as shown in Figure 4. At the highest level, the dendrogram split into two main clusters. Cluster 1, represented by options in purple, yellow, light blue and brown, exhibited a higher potential mitigation value but a lower implementation rate. On the other hand, Cluster 2 consisted of the remaining 59 options (represented in blue, red and green in Figure 4), which had a higher implementation rate but a lower potential mitigation value.

The cluster analysis reveals recurring patterns and significant differences among the clusters comprising the 65 behaviour options. These clusters can be classified into six categories based on variations in implementation difficulty, individual agency, enabling environment, and associated costs at the individual and household levels.

Figure 3. Degree of implementation of the 65 mitigation options during the household experiment.

Figure 4. Clustering of the 65 mitigation options. This data clustering was based on three sets of data: the CFP reduction potential of each mitigation option, their selection rate for the household experiment, and their resulting degree of implementation.

The "Empowered Choices" cluster encompasses behaviours that are comparatively easier to implement or have already been adopted by most participants. These options typically involve small and affordable adjustments to participants' daily lives and routines, requiring minimal financial investment, time, and effort. The suggested behaviour changes primarily rely on individual agency and are minimally hindered by social and infrastructural factors. Additionally, the options in this cluster tend to result in relatively low carbon reduction.

The options in the "Balanced Lifestyle Transformations" cluster required moderate efforts, appropriate timing and initial costs but appeared feasible to most participants. These options are moderately difficult and rely on a supportive environment and higher individual agency for successful implementation.

"Challenging Shifts" compiles behavioural transitions in diets and mobility, which can be seen as highly challenging to most individuals. Such shifts require a high level of personal commitment and a supportive environment to implement, as they can significantly change an individual's habits.

The "Ambitious Investments" cluster is characterised by progressive upgrades in the housing domain, which generally depend on moderate individual agency but require high costs.

Options in "Advanced Innovations" and "Pioneering Sustainability" clusters required substantial investments and a preestablished supportive environment in the housing domain. These options generally required significant commitments such as retrofitting

their home or installing expensive equipment to generate renewable energy at home. Implementation of these options results in the largest reductions in carbon emissions.

This suggested categorisation of mitigation options reflects the general level of effort, personal control, external support, and financial implications associated with each option. However, it is essential to note that this clustering approach is subjective and may vary depending on specific contexts and personal circumstances.

By grouping behaviours based on their difficulty, cost, and required agency, it becomes easier to understand the specific challenges individuals or households may face when attempting to adopt those behaviours. This structured framework can be valuable for prioritising actions based on their mitigation potential and feasibility, enabling effective resource allocation.

Ultimately, this understanding can inform the development of targeted strategies and tailored interventions to address barriers and increase the likelihood of successful implementation. For example, interventions for behaviours in the "Empowered Choices" cluster may focus on raising awareness, providing information, and facilitating behaviour change through small nudges. Behaviours in the "Challenging Shifts" cluster may benefit from interventions targeted at life transitions moments or collective encouragement actions. Interventions for behaviours in the "Ambitious Investments" cluster may involve financial incentives, access to funding opportunities, or support in navigating complex technological choices. Lastly, options in the "Advanced Innovations" and "Pioneering Sustainability" clusters may require a combination of advanced interventions, including deep infrastructural changes, socio-cultural shifts, and financial incentives.

4.3.4. Barriers to 1.5-Degree Lifestyles

For each option, participants were allowed to freely respond to the question: "What barriers did you face when implementing this option?". Responses showed the following:

1. The mobility domain gathered the most responses (552 answers), compared to food (364 answers) and energy (313 answers).
2. The influence of norms and values ("I only go back to my hometown once a year, so I prefer to see my family in person than on an online call"), as well as constraints from work, family, and other social circumstances ("My parents are elderly and do not have internet".).
3. The role of personal preferences and practicalities (i.e., "LEDs are very bright and make my eyes tired"; "I like to cook with a wok, so a gas oven is essential"; I only go home once a year, so I want to be face to face".)
4. Barriers at the household level (i.e., "My parents are too old to go online"; "We live in a two-family house, and it is difficult for us to have a compact house as the children need to concentrate on their studies in their rooms. I live with my son, so I have to eat mostly meat".)
5. Barriers at the workplace level (i.e., "It was difficult to telework as I had to go to work on all days except holidays"; "My workplace is far away, so it is difficult to commute by bicycle".)
6. Barriers at the social level (i.e., "The internet has not yet reached the point where the elderly can live alone"; "Not many people stop idling when they stop their car. There is a lot of traffic congestion, poor driving manners and many parked cars"; "There are not enough places to set up a shared car system".)

The household experiments highlighted the many challenges to realising a 1.5-degree lifestyle. The main obstacles for participants to change their behaviour can be summarised as follows:

1. Lack of infrastructure, goods, and services. For example, it is difficult for people living in rented accommodation to implement option "28. Electrification with IH Cooking Heater + Renewable Energy (Electrification of Cooking)". In areas where there are no cycle paths, it is difficult to implement option "3. Bicycle Commuting".

2. Lack of information when infrastructure, goods and services exist but are not well known by the public. For example, options "38. Switching to 100% Renewable Energy Electricity", "34. Nudging Saves Energy" and "51. Switch to Alternative Meat" are not well known by participants.
3. High costs. For example, the initial costs are estimated to be high for the options "25. Plug-in Hybrid Vehicle", "30. Heating by Air Conditioner", and "32. Thermal Insulation Renovation".
4. Low accessibility. For example, in remote areas with little choice in the number of buses and routes, it is difficult to implement options "5. Bus Commuting" and "11. Private Bus Travel".
5. Conflicts with personal needs. For example, for those who enjoy travelling abroad, there are limits to implementing options "8. Fun in the Neighbourhood", "13. Long Holidays in Japan", and "14. Long Holidays in the Community". Those concerned about the lack of moisture caused by air conditioning or cold feet in winter would not choose the option "30. Heating by Air Conditioner". Those who enjoy cooking Chinese food in a wok would not choose "28. Electrification with IH Cooking Heater + Renewable Energy (Electrification of Cooking)".
6. Conflicts with other people's needs. For example, parents with children of secondary school age and university students who prefer meat are less likely to implement options "49. Diet Centred on Vegetables and Legumes (Vegan food)" and "50. Diet Centred on Vegetables, Legumes, Dairy Products, and Eggs (Vegetarian Diet)". Many people would not choose option "7. Compact-City", depending on the family structure and the age of the children.
7. Conflicts with rules and norms in the workplace, community, etc. For example, it is difficult for people who live in built-up areas of Kyoto to implement options "35. Hot Water Supply by Heat Pump (Eco Cute)" and "36. Hot Water Supply by Solar Water Heater" due to Kyoto's landscape ordinance. It is also impossible to implement option "1. Telework" without permission from the workplace.

4.3.5. Supporting Measures to Achieve 1.5-Degree Lifestyles

Following the household experiments, participants suggested supporting measures or social changes to increase the adoption rate of each mitigation option. Participants were asked: "Based on your experience, what support measures or social changes would increase the adoption rate of the 65 options?". Table 4 shows some examples of the typical supporting measures for the options of "1. Telework", "41. Zero Energy House (ZEH)" and "55. Local production and local consumption of vegetables".

Upon review, responses on supporting measures were divided into seven categories: "Socio-cultural transformation and transition" (societal aspects such as institutions and values), "Improving infrastructure or implementation environment" (logistical and technical support in the form of infrastructural facilities and equipment), "Economic incentives", "Improving products and services", "Providing and disseminating information", "Providing learning opportunities and capacity building", and "Others".

With 364 supporting measures, "Economic incentives" was the largest category, closely followed by "Socio-cultural transformation and transition" with 355 supporting measures. Many other supporting measures were classified as "Improving products and services" (287), "Improving infrastructure or implementation environment" (286) and "Providing and disseminating information" (232), and fewer measures were related to the "Providing learning opportunities and capacity building" (140). Other responses, which could not be categorised in any of these groups, were classified as "Other", with 81 responses. Many options carried several aspects and were thus placed into multiple categories.

Table 4. Supporting measures for lifestyle change.

Lifestyle Change Option	Supporting Measures					
	Socio-Cultural Transformation and Transition	**Improving Infrastructure or Implementation Environment**	**Economic Incentives**	**Improving Products and Services**	**Providing and Disseminating Information**	**Providing Learning Opportunities and Capacity Building**
1. Telework	• Adjust working rules and regulate teleworking achievement rates • Awareness raising for managers and supervisors • Creating a working environment in surrounding areas	• Provision of PC etc. • Securing co-working spaces • Better access system and Security measures • Improvement of nursery schools	• Financial support for the development of the environment • Preparatory funds for companies • Support for housing relocation	• Low-price and high-quality IT equipment, applications and service • Consultation service	• Information provision on how to improve teleworking conditions	• Conduct tours and briefing sessions
41. Zero Energy House (ZEH)	• Collaborate with estate agents • Regulation of new residential properties		• Subsidy to reduce installation costs	• Development of low-cost, high-performance products	• Provision of information on economic implications	
55. Local production and local consumption of vegetables	• The utilisation of abandoned farmland	• Improvement of distribution of local vegetables		• Improvement of varieties suitable for open-air cultivation • Development of attractive recipes	• Promotion of exchange between producers and consumers • Promotion of food education	

(Adapted from Kyoto in 2030: Envisioning 1.5-Degree Lifestyles [11] and Yokohama in 2030: Envisioning 1.5-Degree Lifestyles [15]).

Some of the categories, such as "Economic incentives" and "Socio-cultural transformation and transition" can be subdivided into measures that should be promoted and those that should be avoided. For example, in the "Economic incentives" category, respondents proposed introducing a discount system to encourage public transport for long-distance journeys and a subsidy system for net-zero-energy housing retrofits. On the other hand, many respondents suggested that the purchase of cigarettes and alcohol should be discouraged by increasing taxes on those items, and a carbon tax on car fuel would encourage a shift to low-carbon alternatives. Regarding "Socio-cultural transformation and transition", several respondents pointed out the importance of promoting the traditional Japanese concept of "Mottainai", which captures the idea of valuing resources and avoiding wasteful behaviours to curb the current culture of mass consumption and mass disposal.

Suggestions collected from participants offer guiding principles to support adopting mitigation measures in each of the five domains.

- Mobility: Improving public transportation and cities' transportation infrastructure

For the "Mobility" domain, proposed mitigation measures largely depend on "Improving infrastructure or implementation environment", "Economic incentives", and "Socio-cultural transformation and transition". Most of the 728 suggestions for this domain focused on public transportation. Participants' responses reflected demands for the transport network to be improved, the frequency of trains and buses to be increased, and cost subsidies to be provided. Regarding bicycles, there was a strong call to develop cycle lanes. Changes to society are also expected, such as the development of more compact cities, the transition to slow lifestyles and telework. Additionally, expanding the sharing economy, including carpooling services, is expected to offer increasing low-carbon mobility services.

- Housing: Leading incremental changes towards the development of carbon-negative housing

The "Housing" domain, related to the use of home appliances, such as heating and cooling, hot water supply, electricity, and housing, gathered 395 suggestions. Most suggested support measures were categorised as "Economic incentives", "Improving products and services" and "Providing and disseminating information". Some of the options in this domain were relatively easy to implement during the experiment, such as window insulation or consumption feedback systems through smart meters. Other mitigation options, such as providing hot water through heat pumps and life-cycle carbon-negative housing, required more effort. Many of the respondents declared that they were unfamiliar with many of the mitigation options in the energy and housing domain. This highlights the need for manufacturers to communicate about these low-carbon alternatives more effectively to the public and conduct tours and briefing sessions to demonstrate their implementation in practice.

- Food: Promoting healthy consumption while preventing waste

In the "Food" domain, mitigation options, including reducing excessive eating, drinking, and smoking, and preventing food waste, gathered 380 suggestions for supporting measures from respondents. Supporting measures were focused on "Providing and disseminating information", "Providing learning opportunities and capacity building", and "Socio-cultural transformation and transition". Some respondents suggested indicating information such as nutritional value, place of origin and seasonal period on food packaging to promote healthier food consumption and imposing stricter regulations on cigarettes and alcohol sales. Providing ready-made healthy meals in supermarkets and possibly taking leftover food home was also encouraged. A societal shift towards a slower lifestyle was also put forward to encourage people to cook for themselves.

- Products: Encouraging reuse and sharing through socio-cultural changes

There were 186 suggestions for the 'Products' domain aiming to reduce the number of new products produced and purchased. The most common supporting measures were related to "Socio-cultural transformation and transition", "Improving infrastructure or implementation environment" and "Providing learning opportunities and capacity building". While most respondents suggested having flea markets and sharing apps to encourage the reuse of long-lasting goods, many also called for socio-cultural changes to bring back traditional 'Mottainai' values. However, some respondents also shared their concerns over the safety of second-hand goods for electrical appliances and the impact on the publishing industry regarding sharing books and magazines and using libraries and e-books.

- Leisure: Promoting local and sustainable tourism

There were 56 support measures related to the "Leisure" domain, which promotes local tourism and low-carbon activities. Many respondents suggested that providing and disseminating information on local activities and organising events locally would encourage people to rediscover their region and find unique activities, with the added benefit of maintaining a low budget. Other respondents suggested a more economical approach, such as discounts for residents and issuing local vouchers. In addition, developing and improving local leisure facilities such as libraries, bicycle lanes, and parks were crucial for encouraging local tourism. As travelling overseas was restricted due to the pandemic during the household experiment, travelling domestically and enjoying the local area appeared to be widely accepted by participants.

5. Summary and Recommendations

5.1. Identifying CFP Hotspots in Relation to Consumption Domains and Socio-Demographic Characteristics

This study estimated participants' energy consumption and quantified the impact of greenhouse gas (GHG) emissions from various consumption data across housing, food, mobility, products, leisure, and other domains. The statistical analysis aimed to investigate the sociodemographic characteristics of individuals with high and low carbon footprints (CFP), but no significant difference was found in the total CFP scores. However, when

analysed by specific domains, significant differences were observed between individuals with high and low CFP. In the "Mobility" domain, households with fewer members, unemployed individuals, and individuals with lower household incomes showed a lower CFP. In the "Food" domain, individuals in relatively younger age groups, living in rental housing, and residing in suburban areas had lower CFP, while those who were conscious of food waste also exhibited lower CFP. Additionally, in the "Other (Services, etc.)" domain, individuals with a larger family and those with higher household incomes tended to have higher CFP.

This analysis demonstrates how carbon footprints can vary based on individual differences such as age, income, housing type, family composition and employment status. Particularly, the analysis of CFP allows the identification of GHG emission hotspots within each domain and sociodemographic segments. This information is essential for identifying key regions and groups where efforts can be concentrated to achieve maximum mitigation effects.

However, it is essential to note that the sample size used in this study was relatively small, limiting the generalisability of the survey results to a larger population and preventing meaningful comparisons between cities and within categories. To address these limitations, future research should collect more data through random sampling to increase the generalisability of the findings to a broader population.

5.2. Determining Barriers and Supporting Measures to 1.5-Degree Lifestyles

Understanding the barriers and preparedness required for adopting a 1.5-degree lifestyle is crucial for developing targeted support measures and long-term mitigation strategies. Examining the barriers and preparedness levels identified by participants in household experiments shows that these factors are intricately interconnected.

The survey responses revealed several external barriers to adopting 1.5-degree lifestyles, such as the lack of adapted infrastructure, low-carbon goods and services, and their limited geographical and financial accessibility. From this perspective, policy and business efforts should continue to focus on developing technological innovations, designing better products, and providing infrastructure for collective use.

Other barriers identified during the study are related to internal factors within individuals and households. The lack of knowledge of how and why to undertake specific sustainable actions was a commonly given barrier. An initial supporting measure is thus the provision of information to raise awareness of the benefits of lifestyle changes [4]. Nevertheless, as the provision of information is often insufficient, it is essential to engage individuals effectively with sustainable lifestyles to stimulate excitement about the prospect of new ways of living. Axon identified several interventions to engage individuals, such as campaigns, events, and pop-up shops [4].

Another barrier arises from individuals facing immediate and pressing everyday concerns, leading to the relatively low priority of environmental issues that may conflict with their other personal needs. The internalisation of personal norms based on anticipated guilt and negative emotions related to social norms significantly predicts attitudes and perceived behavioural control towards low-carbon actions [5,6,31]. However, maintaining certain values does not necessarily lead to more sustainable behaviours. A 'value-action gap' can arise due to situational or psychological constraints in daily life [7]. This is primarily due to the perceived inconvenience and high cost of more sustainable actions in a "time-pressured" society. Furthermore, numerous psychological, sociological, economic, socio-political, infrastructural, and institutional barriers can make it difficult to change everyday behaviours. Therefore, significant life course discontinuities, such as moving to a new residence, which temporarily disrupt established habits, could serve as "windows of opportunity" for behaviour change interventions [32].

Other people's needs and societal norms were highlighted as the main barriers. To avoid the feeling of "powerlessness", individuals engaged in sustainable lifestyles were shown to find comfort in other actors, such as their community, businesses or govern-

ments undertaking similar commitments. The importance of collective action was often highlighted as a critical component of sustainable living in the long term [4,22]. Group dynamics are essential in providing a sense of efficacy and belonging to encourage sustained behaviour changes [27]. Participatory policymaking processes also provide a crucial approach to overcoming such barriers by uncovering peoples' differing needs and desires [3]. However, it should be noted that barriers can differ based on group or cultural divisions, and individuals may respond differently to various types of messaging. Facing multiple barriers may increase one's amotivation to act or change behaviour [7].

Each barrier to behavioural change may be difficult or even impossible to address individually, highlighting the need for comprehensive societal transformations. A fundamental re-evaluation of the entire social and economic system that governs the transition to a low-carbon and sustainable society is necessary. From this perspective, it is essential to clarify the responsibilities of all significant stakeholders, envision solutions, pilot and mainstream alternative infrastructure, and develop the capacity to shape consumer choices and lifestyle patterns. Table 5 combines the barriers participants face when implementing low-carbon options at home and the suggested supporting measures and enabling contexts needed to overcome them. Furthermore, the table proposes the responsibilities that local government, businesses, citizens, and civil society can adopt towards facilitating supporting measures and enabling contexts for 1.5-degree lifestyles and societies. This may provide the basis for policy recommendations.

Table 5. Roles of stakeholders to enable lifestyle changes and realise the desired future given the above challenges and recommended supporting measures.

Obstacles	Enabling Contexts	Recommendations to Stakeholders		
		National and Local Governments	Businesses	Citizens and Civil Society Organisations
Infrastructure, Service or Goods do not exist (e.g., Rental Zero-Energy Houses)	Infrastructure, Service or Goods are provided	• Reviewing regulations • Infrastructure development • Investment promotion • Public procurement	• Provision of goods and services • Joint development of goods and services with governments & citizens • Services improvement	
Infrastructure, Service or Goods exist but are not well known (e.g., 100% Renewable Energy Contract)	Information on infrastructure, services or goods are provided	• User-friendly information provision • Labelling • Media campaign	• Provision of user-friendly information • Consulting services (e.g., houses, transportation) • Provision of search/mapping engines, mobile apps, etc. • Events	• Joint event with local governments or businesses
Infrastructure, Service or Goods exist but are too expensive (e.g., Zero Energy Houses)	Affordable Infrastructure, Service or Goods	• Tax reform • Subsidy • Price regulation	• Provision of more affordable goods and services	
Infrastructure, Service or Goods exist but are too difficult to find and access (e.g., Vegan Foods, Car sharing)	Infrastructure, Service or Goods become more easily accessed andobtained	• Support citizens and businesses to create more accessible goods or services	• Provision of search services, mobile apps, etc.	• Mapping goods and services in cooperation with local businesses, co-ops, etc. • Identifying locally available goods and services

Table 5. *Cont.*

Obstacles	Enabling Contexts	Recommendations to Stakeholders		
		National and Local Governments	Businesses	Citizens and Civil Society Organisations
Taking the option might conflict with other daily needs (e.g., Commuting to the workplace by bus)	Availability of options meeting different needs simultaneously	• Support citizens and businesses to create and share options	• Services improvement • Joint development of goods and services with governments and citizens	• Group buying • Joint development of goods and services with governments and businesses (e.g., Living lab) • Sharing citizens' wisdom
The option conflicts with others' needs (e.g., Online home visits do not satisfy grandparents, Vegetarian diets may be good for parents but questionable for children)	Availability of options meeting the needs of different people simultaneously	• Increase participatory processes in policymaking. • Support citizens and businesses to co-create and share options. • Provide a platform for citizens to provide feedback and ideas on policies and governmental initiatives	• Services improvement • Joint development of goods and services with governments and citizens	• Joint-development of goods and services with governments and businesses (e.g., Living lab) • Communicate local needs to other stakeholders
The option does not follow the informal rules or norms of the community or workplace (e.g., Adjusting clothes, Difficulty to install rooftop PV in historical areas)	Informal rules and norms are revisitedand modified for encouraging low-carbon actions	• Support community actions • Encourage businesses to change office rules. • Initiate public-citizen collaboration	• Services improvement • Joint development of goods and services with governments and citizens • Joint event with citizens' groups and communities	• Local events and workshops • Revision of rules in cooperation with governments and business

(Adapted from Kyoto in 2030: Envisioning 1.5-Degree Lifestyles [11] and Yokohama in 2030: Envisioning 1.5-Degree Lifestyles [15]).

The "1.5-degree challenge" household experiment provided valuable practical insights regarding the transition to decarbonised lifestyles. However, the brief experiment (over two weeks) implemented by participants does not provide lessons on the long-term dynamics between practical constraints and daily life priorities. Further, although the 65 mitigation actions presented by the workshops covered a wide array of changes to lower participants' carbon footprint in various domains, many other behaviour changes are yet to be tested and evaluated in this context, such as water-savings, environmentally friendly cooking, eco-bags, and more. It is also important to note that the implementation of the challenge was often hindered by the unavailability of infrastructural facilities, goods, and services necessary for their experimentation. The provision of material and financial support to test the implementation of low-carbon behaviours could reduce such implementation barriers in this experimental phase. Nevertheless, the limitations encountered by participants can be highlighted as key remaining barriers to be solved by partnering with local governments and businesses to facilitate a faster and wider transition to low-carbon lifestyles. With these caveats in mind, lessons learnt from the workshops and 1.5-degree challenges offer useful insights for practitioners and businesses seeking to promote low-carbon and sustainable living.

6. Conclusions

This study provides a quantitative analysis based on the results of 1.5-degree lifestyle workshops and household experiments conducted in four cities in Japan. First, it highlights the variation in carbon footprints based on socio-demographic characteristics, emphasiz-

ing the need to focus on key regions and groups to achieve maximum mitigation effects. Additionally, it identifies the barriers to adopting a 1.5-degree lifestyle and proposes support measures to overcome them. The findings from the collected responses indicate the importance of individual norms and preferences in determining the feasibility of mitigation options. However, it also reveals that infrastructure limitations, high costs, and conflicting social and workplace norms are major obstacles to the adoption of mitigation actions. As a result, support measures focusing on promoting socio-cultural transitions, improving infrastructure/products/services, and providing economic incentives are suggested. Partnerships with local governments and businesses, promoting collective action and participatory policymaking, are emphasised to effectively address implementation barriers and accelerate broad societal changes towards low-carbon living.

The IPCC AR6 WG3 report emphasises the need for a comprehensive transformation of the social-economic system that mobilises various drivers, including individual behaviour change, sociocultural changes, businesses, institutions, and infrastructures, to meet basic needs while reducing carbon emissions. Raising awareness is insufficient, and local governments and other actors must develop and validate effective methods for facilitating lifestyle changes through transforming service provision systems. To achieve the goal of a 1.5-degree lifestyle, it is essential to adopt a co-evolution and co-creation approach, engaging diverse stakeholders. Individuals and households are not only the recipients of decarbonisation agendas but also important actors who guide governments and businesses in providing supportive measures to facilitate action. Enabling consumer behaviour change requires aligning motivation, resources, and opportunities, which can be facilitated through collaborative efforts between governments, businesses, citizens, and civil society organizations. Governments should reduce long-term sustainability-oriented changes by revising regulations, overcoming entrenched beliefs, and providing appropriate infrastructure and policy environments. The business sector is crucial in proposing innovative business models that offer sustainable and low-carbon products and services to meet consumer needs. Citizens can contribute by exercising their agency for sustainable consumption and participating in co-creation processes with governments and businesses. Communities, workplaces, and schools can contribute to the short term changes through grassroots initiatives and outreach activities.

Furthermore, as emphasised in this paper, it is crucial to translate knowledge into practical applications and support real transitions, especially at the local level. The insights and methodologies obtained from this study can serve as valuable reference materials for similar initiatives overseas. Promoting these practices make it possible to contribute to establishing an enabling environment for the transition to a decarbonised society. However, while this study provides practical insights, it also acknowledges the limitations of short-term experiments and the need to further evaluate long-term dynamics and additional behaviour changes. The IGES research team will continue to deepen the understanding of practical methodologies and feasible policies, promote co-learning and co-creation approaches through partnerships with various stakeholders, and drive the transition towards a sustainable society.

Supplementary Materials: The following supporting information can be downloaded at: https://www.iges.or.jp/en/pub/1-5-lifestyles-catalogue-japan/en (accessed on 28 May 2023), Catalogue of 1.5-Degree Lifestyles Options.

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