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Leveraging realities of saving energy at home: Contributions of co-design to behavioural interventions

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ABSTRACT

While reducing individual energy consumption contributes to climate change mitigation, many individuals who share this belief fail to act on it. While behavioural interventions try to address such intention-behaviour gaps, few approaches have worked *with* consumers to understand the realities of their opportunities and limitations to save energy at home. We argue that co-design is well-suited to address the unique challenges of climate-relevant behaviour change and propose an abductive co-design methodology to develop a behavioural intervention with household members based on the Model of Action Phases (MAP) framework. We implement the methodology to design an energy savings app and behaviour change intervention in Switzerland. The methodology shifts participants into an expert role and elucidates their motivations, real-life challenges, and knowledge gaps to save energy. Through group problem-solving and self-reflection, participants provided design inputs which address the socio-psychological gaps to progress behaviour through the preaction, action and postaction phases of the MAP. We assess the originality and feasibility of the co-design inputs, as well as reflect on the experience of the researchers and participants during the process. We conclude that co-design provided novel inputs relevant for progressing through the behaviour change stages identified by the MAP framework.

1. Introduction

The way individuals consume energy, that is when and how much is consumed, is a relevant aspect of climate change mitigation [1]. Thus, much research in the past three decades has focused on how to change towards pro-environmental behaviour (see reviews from [2–5]). Herein, the Model of Action Phases (MAP) framework, originating in psychology, offers a temporal framework identifying where someone is within a change process, that is at predecision, preaction, action, or postaction of the desired behaviour [6].

The MAP framework can be used to guide the design of behavioural interventions to address people where they are at in their process of change. If someone is at the predecision stage, it is essential to support social and personal norms and perceived responsibility, as well as economic value for enacting energy saving behaviour [7]. Whereas at the preaction or action phase, the model suggests increasing perceived behavioural control, environmental attitude, intention, and skills through interventions which focus on knowledge building or goal setting, for example [7]. Furthermore, the change should be supported in a postaction phase through reminders, renewed goal setting, or community support. Finally, as relevant climate impact only arises when many people take such a step, approaches should address groups of people, like families, communities, teams, etc. [8].

Recent calls for improving intervention impact [9] and inventiveness in experimental design [10] ask for implementing new approaches which address persisting challenges at the preaction, action and postaction MAP phases. Despite a growing awareness that consumption behaviours need to change, a persistent intention-behaviour gap [6,11] occurs in the preaction phase and individuals rarely enter the action phase (e.g. as seen in ethical consumption behaviours [12,13]). Further, participant drop-out (attrition) remains a challenge in maintaining engagement to support the behaviour change during the intervention

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(action phase) [14,15], as well as maintaining the behaviour change in the long-term (postaction phase) [16]. These challenges, which are inherently user-centric, suggest exploring novel approaches aimed at enhancing the fit of an intervention to a user's context and interests.

One such approach, co-design, has begun to emerge as a new possibility to integrate the target users of behaviour change into intervention design [17–19]. Co-design is a process of bringing together designers and users to create an outcome of higher value than if only one entity (i.e., a person, team or company) worked on their own [20]. In energy behaviour change research, the process shifts the researcher away from defining the problem and solution alone, and integrates energy consumers as "domain experts" in the research design process. Thus co-design offers a reflexive approach to improve the researchers' ability to design more effective and engaging interventions [19]: by incorporating the perspective of the intervention target users themselves, persistent user-centric challenges can be more effectively addressed. Herein, an abductive approach to co-design integrates theory-based approaches from researchers and contextual knowledge of consumers to potentially improve effectiveness of behaviour change interventions, while also enriching the application of theory [21] (additionally, see [22] for why theory-informed impact is needed). Such an approach is also expected to empower consumers and create a sense of community [23], thus producing much broader positive effects that go well beyond the specific interventions under development.

In this paper, we answer the research question: How does a co-design process contribute to an energy savings intervention based on the MAP theory of behaviour change? For this purpose, we first develop a process for co-designing a behavioural intervention following the MAP framework. Such a co-design process aims to leverage consumers' needs, motivations, and challenges to change behaviour and integrates these directly into the MAP framework. We then implement and assess the process in a case study co-designing an app-based intervention for at-home energy savings with household energy consumers in Switzerland. To answer the research question, we analyse our case study focusing on three aspects. First, we critically assess the contribution of such a directed co-design process to provide new design inputs addressing challenges at the preaction, action, and postaction MAP phases. Secondly, we present the participants' assessment of the co-design process and resulting prototype of the app-based intervention design. Finally, considering that the co-design process itself may influence participants through the act of reflecting on their own needs, motivations and challenges, we explore the effect of participation on individual attitudes towards energy savings. Understanding the relevance of the process to the participants can support co-design processes in the future.

The article is organised as follows: Section 2 summarises insights on the value of co-design processes and learnings from previous app-based behavioural interventions in the energy domain. The section ends with how to integrate co-design into theory-based intervention design. Section 3 illustrates our methods and case study: it first presents the co-design process we developed for a behavioural intervention based on the MAP framework, followed by the assessment methodology we adopted. Then, it details our implementation case about an app-based energy savings intervention. In Section 4 we present the results of implementing the co-design process for the case study, by summarising the participants' contribution to the design and the practical implications, the participant's assessment of the co-design process and outcome, and any effects on the participants due to their participation. In Section 5 we discuss the relevance of co-design on the intervention design and reflect on the process and in Section 6 we conclude and provide suggestions for future research.

The app and accompanying behavioural intervention resulting from the co-design were tested in a real-world experiment in 2022–2023. This paper focuses only on the co-design process and hence does not cover the implementation of the behaviour change intervention on the field, nor evaluate its impact.

2. Background

2.1. Co-design for sustainability

In their seminal paper on co-design, Sanders and Stappers [20] outline the evolution of designing products and services with the people who would be the final users or consumers of the design. These participatory and collaborative practices, broadly named co-design, range in their extent of input, ownership, decision-making power, etc. and usually involve a mixture of trained professionals (e.g. with disciplinary or expert knowledge) and citizens (e.g. expert of their own experience or local knowledge). Co-design processes are differentiated by the project setup, type of engagement and the agency of the different actors involved, but are not specific to any discipline, product, or service [24].

While still evolving as a practice, varying greatly with context, and without a robust evaluation method, co-design processes have been applied in various sustainability fields [19,23,25–29]. Itten et al. [19] argue for the use of co-design in transitioning to more sustainable heating systems because it can overcome the persisting socio-economic-political hurdles through more inclusion of different voices, better distribution of benefits, higher trust and transparency, and room for experimentation. Sanders and Stappers [20] note that these approaches change the initial problem definition and idea generation of the collaborators in ways that allow for larger scale and deeper transformation, and could ultimately lead to more sustainable ways of living.

Co-design is a design approach which prioritises experiential knowledge from the citizens or users in idea and solution development [30]. The designers or research team guide the process with facilitation tools and support making ideas implementable. The co-design process often involves multiple steps to develop a mutual understanding (knowledge dissemination), defining problem and solution scope (knowledge sharing), and generating ideas for the desired outcome (knowledge creation) [24]. The process is iterative, involving phases of sensitization to the issue [31] followed by generation of ideas about the problem and solution [32]. Practically, there are many methods to elicit and create knowledge between the different participants in a co-design process in a workshop setting, such as storytelling of the current situation using pictures, icons, shapes, etc. [24]; developing user journeys based on defined personas [33]; or creating prototypes with simple materials (e.g., building blocks, cardboard, clickable digital interface, etc. [34]). Further methods have been systematically collected and defined by the European Network of Living Labs [35].

Challenges exist in evaluating co-design processes as they are heterogeneous, context dependent, and time and resource intensive. Thus, co-design is not evaluated using standard scientific approaches, such as through exact replication or comparison to control groups [36]. In bringing together researchers and citizens, the process challenges the traditional separation of beliefs, emotions and ideas, from facts, rational consistency, and objectivity [37]. However, the resulting complexity, while potentially rich in insights for behaviour change researchers, can challenge the integration of results into theory-based approaches. As co-design continues to evolve as a practice purporting innovation through inclusiveness, critics have argued that it may not be a pragmatic choice due to the time and resource intensity of engaging different actors [38]. Hence there is a need for further investigation of the potential benefits of co-design processes and their outcomes.

2.2. Behaviour change apps for sustainable energy consumption

In the last decade, smartphone apps have grown in use, both in scientific and commercial contexts, to encourage more sustainable energy consumption through novel, timely and personalised information feedback [39–41]. For example, there are apps which estimate energy consumed when showering, by measuring water volume and temperature using a Bluetooth-enabled in-line shower meter [42] or provide energy savings recommendations and incentives based on real-time feedback from household energy consumption, measured by smart meters [43]. Overall, meta-reviews of intervention studies have found smartphone apps to be successful in facilitating behaviour change [40].

Broadly, smartphone apps are a medium to intervene in the user's everyday reality and leverage this engagement to provide persuasive feedback that influences user behaviours [44]. Thus, a specific theory of behaviour change can be operationalised as an intervention in an app using different design features. For energy consumption, the aim is to trigger, motivate, and maintain new patterns of energy use which last beyond the intervention period [7]. Herein, the Model of Action Phases (MAP) [45] highlights the cognitive processes before, during and after the behaviour is enacted, and thus has inspired this specific methodology for intervening in daily sustainability-relevant behaviours [6].

The MAP framework denotes behaviour in four phases: predecision, preaction, action and postaction (Fig. 1). The framework associates relevant socio-psychological factors (e.g. attitudes, intentions, or social norms) which help move the behaviour forward through the phases [7]. The framework combines various theories of behaviour change, with the most important being [6]: 1) the activation of personal norms in the Norm Activation Model [46], to elicit reflections and feelings about one's actions, and 2) increasing perceived behavioural control from the Theory of Planned Behaviour (TPB) [47], to support aligning one's actions with one's environmental attitude.

For a behavioural intervention, the MAP framework can address a diverse group of individuals, who may be at different phases, using phase-specific factors. As this study focuses on the preaction, action, and postaction phases, there are five socio-psychological factors that are relevant to progress behaviour forward (Fig. 1) [7]. In the preaction phase an individual is motivated to set an intention to do the new behaviour. The first factor in this phase is *perceived behavioural control*, which describes the ease someone has to perform the desired behaviour. Originating from TPB, perceived behavioural control implies that someone has the required opportunities and resources, and holds a belief of self-efficacy to fulfil the desired behaviour [47]. The second factor is the individual's *attitude* towards the behaviour, which necessarily should be positive to support the setting of the intention, as shown in the TPB [47]. In the subsequent action phase, the behavioural intention is operationalised into a precise and contextual implementation intention, which involves activating *action planning*, as well as *coping planning* when obstacles arise. Improving action and coping planning involves skill building and addressing habitual patterns [6]. The final phase, postaction, necessitates increasing an individual's *ability to recover from setbacks*, to continue to implement and maintain the new behaviour despite obstacles or occasional failure [7].

Considering the MAP framework, three specific user-related challenges exist which relate to the preaction, action and postaction phases. At the preaction phase, the so-called intention-behaviour gap [11,48] is most challenging. Here, awareness of the impacts of energy consumption on climate change or even the benefits of energy savings may be present, yet the subsequent energy saving behaviour does not take place. Herein, theories purporting rational behaviour change fall short, thus interventions could consider what is particularly relevant at this phase to trigger a new behaviour [49]. Many sociologists argue that the environmental context in which a behaviour occurs (e.g. considering the social relations, available infrastructure, institutional processes, etc.) impacts the execution of behaviour, as well as the person's ability (self-efficacy and perceived behaviour control) to change their behaviour [50]. Further, targeting intention alone will not necessarily lead to a long-term behaviour change, and thus interventions should consider behaviour change through to the postaction phase [6].

During the action phase, when an intervention may be motivating a new behaviour, app users can lose interest and drop-out, highlighting the general problem of participant attrition in behavioural interventions [14,15]. A lack of awareness regarding the potential benefits of the behaviour change can lead to disengagement [15]. When these aspects are left out, an intervention may be ill-fitting or hard to engage with for the user or fail to support continuation of the behaviour and thus contribute to high intervention attrition and loss of effect.

Finally, the new sustainable behaviour must be maintained in the postaction phase, but rarely are interventions designed for this phase [40]. Thus users can relapse back to the previous behaviour while in the postaction phase [51]. It cannot be expected that a behaviour becomes an engrained habit during a short-time intervention and thus maintenance of the desired behaviour requires continued support after the intervention [7]. Frey and Rogers [16] suggest pathways to support maintaining behaviour in the long-term, including providing reminders connected to environmental cues to create associations to the new behaviour or changing people's beliefs, attitudes and interpretations about the impacts of their behaviours.

Considering these challenges, realizing the potential of app-based behaviour change may require more user involvement in the design [52–54]. Thus, co-designing behavioural interventions may be a promising approach to tailor an intervention to the potential user's attitudes, motivations and realities, and therefore result in greater energy saving effectiveness [19,28,55].

Also, it may be more effective to not look at consumption patterns in isolation, but rather within the context of the daily behaviours which household members are already engaged in, which need to be derived from the household members themselves [40,56]. These challenges align with the earlier call from Buchanan, Russo & Anderson [57] to design for the human components of information feedback, that is considering context, motivation, knowledge, and engagement. Overall, we believe co-design approaches are well-suited to address these types of challenges.

2.3. Integrating co-design into theory-informed intervention design

We propose that co-design can be used in the design of a behavioural intervention using an abductive approach, i.e., an iterative process of exploring, developing and evaluating ideas for a problem with researchers and the potential behaviour changers [58]. Hurley et al. [21] provide guidance on an abductive approach to adapt the co-design process to effectively integrate research theory and experiential knowledge. Through a reflexive facilitation process, they have found

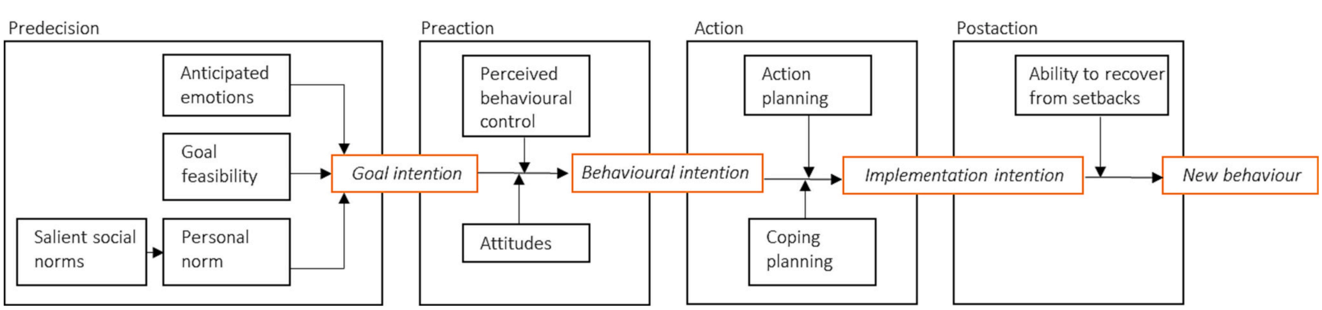

Fig. 1. Conceptual schematic of the Model of Action Phases (schematic after [7]).

that intervention design was enhanced, particularly during the initial "fuzzy" stages of design. Therefore, we will use this approach to develop a co-design process for behavioural interventions following the MAP (further described in Section 3.1).

A behaviour change intervention is defined as "a coordinated sets of activities designed to change specified behaviour patterns" [59]. Thus, in this context activities are intervention techniques and design features with an app, such as social comparison or feedback on consumption impacts. Thus, the choice of the activities which induce a behaviour change can benefit from knowledge of temporal and spatial factors which might enable or impede the user.

Additionally, co-design can support designing to address existing challenges. For example, engagement with an app can be related to the frequency, novelty and relevance of the information provided. Thus, intervention design should consider how to maintain interest in consumption impacts, considering that the novelty of electricity consumption data feedback decreases with time since it is quite repetitive [60]. Importantly, the users involved should be strategically chosen in order to represent the full range of the target group(s) for the product or service to be designed, as opposed to aiming for representative or complete participation [27].

There is no standard assessment of the value of the new design inputs resulting from the abductive approach. However, relevant criteria can be defined in advance or developed with the research team and the users as part of the co-design process [18,61]. While some studies focus on the value added to the product, users, or other actors involved [62], most studies assess design inputs based on their originality, user value, and feasibility [18,28,63,64]. Within the few quantitative empirical assessments, inputs from the users in a co-design process were significantly more original than inputs solely from the research team [63] or those from users not in a co-design process (e.g., those asked for inputs by survey) [64]. However originality and feasibility tended to be inversely related, as more novel inputs may be less feasible to actually implement (i.e. out of scope, more expensive to execute, less practical) [63].

We take these considerations for design and assessment into account for the abductive methodology to integrate co-design in a behavioural intervention based on the MAP framework.

3. Methods and implementation case

In this section we outline the co-design process, the assessment approach, and the implementation case to answer the research question on how co-design contributes to a behaviour change intervention designed following the MAP framework.

3.1. The co-design process

The co-design process we developed aims to gather concrete proposals for the intervention design through iterations between the participants and the research team and is based on earlier co-design processes in the field of sustainable energy behaviour change [19,26,28,29]. It is initiated at the start of the intervention design process and involves the research team, volunteers of the target population (i.e., the participants), and domain experts that are relevant for the specific behaviour in focus.

The time schedule of activities of the co-design process is presented in Fig. 2. We suggest co-design activities begin with an online survey to characterize the co-design participants, followed by two workshops facilitated by the research team, to *Discover* and *Design* the behaviour change intervention. These activities follow the context mapping approach of Visser et al. [31], wherein sensitization to the topic is followed by the participants generating their own ideas, and then analysis by the project team.

The *Discover* workshop should first introduce the participants to each other and the research team and establish a code of conduct to encourage a comfortable workshop atmosphere. The workshop content can begin with background information on the behaviour in focus and continue with a detailed presentation of similar interventions already performed, to provide inspiration. This sensitization step is important to introduce the topic, as well as the theories being applied by the research team [21]. Live survey tools can be used to enable quick and anonymous feedback during the workshop and to stimulate short discussions in order to explore the results in more detail.

The second workshop *Design* should ideally be held within a few weeks of the first workshop. Here, the goal is to use generative methods [32] to facilitate exchange between the participants and the researchers and collect design suggestions for the intervention. Outputs from the

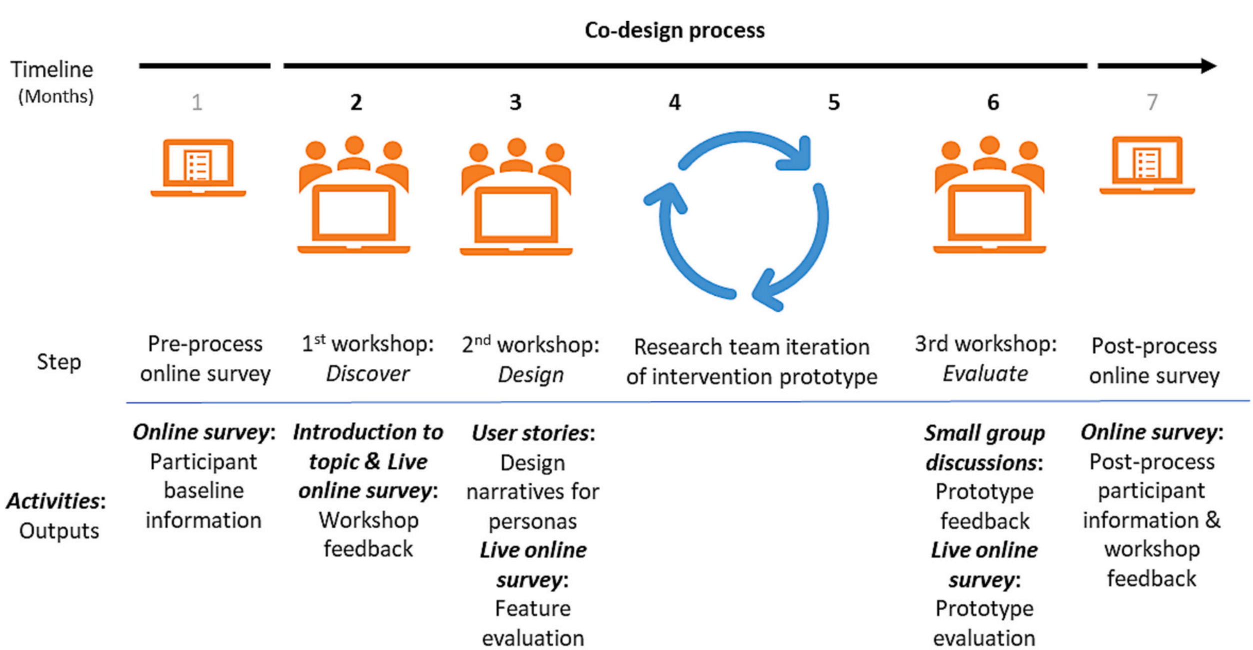

Fig. 2. The co-design process: all activities involve participants and researchers, except for the prototype iteration by the research team.

Design workshop need to be compiled and reviewed by the research team and the experts from the field, to develop a proposal for the intervention design.

Based on these initial workshops, the research team and domain experts prepare an intervention prototype to present to participants in the *Evaluate* workshop. The resulting prototype is discussed and evaluated by the participants to get their feedback and suggestions to further enhance the design.

Overall, the workshops aim to reveal participant's needs, motivations, and challenges to save energy. The research team needs to identify how to best integrate the participant's inputs into the MAP process to increase chances for progress between preaction and action phases and maintain the behaviour in the postaction phase.

3.2. The assessment of the co-design process

To assess the effectiveness of our proposed co-design process, we consider three aspects: i) originality, feasibility, and fit of participant inputs along the MAP action phases, ii) participants' assessment of the co-design process, and iii) impact of the process on participants as a collaborative experience. To assess these aspects for the implementation case, we collected qualitative information during the process, as outlined in Table 1. Each workshop was recorded and we used different online tools to collect inputs from the participants in both individual, small group, and full group sessions, as depicted in Fig. 2.

To assess the inputs from the process, a written record of the discussions in each workshop was compiled by the researchers. Qualitative content analysis [65] was used to analyse the records of all workshops, and we inductively created design categories based on the inputs from the participants. Furthermore, the inputs were mapped onto the MAP to assess the new contributions to each phase, and the research team and domain experts qualitatively assessed the feasibility of each input.

To collect the participants' perspective, two online surveys were completed by participants, before and after the series of workshops (as seen in Fig. 2). Questions in the surveys asked the participants to assess the whole process and allowed the research team to estimate the impact of the process on the participants: specifically, home energy system awareness and attitude towards energy use were measured [66]. It was expected that participants, analogous to the target population, likely already have the intention to save energy, but are not sure where to start or how to make an impact –namely, they are in preaction phase. Observing a change in their attitudes between the first and the second survey could thus imply a behaviour change process has started, namely an increase in the chances that they will form a behavioural intention and enter the action phase of performing energy saving behaviours [6]. However, note that the co-design process is not an experimental treatment in itself and did not envision a control group. Therefore, no causal interpretation can be performed and possible observed changes in awareness or attitudes (and in consequent behaviour) cannot be uniquely attributed to participation in the co-design process.

Table 1
Summary of the assessment items, the indicators considered, and the data sources used.

Assessment items	Indicators	Data source
i) Design contributions of participants to the preaction, action and postaction phases of the behaviour change intervention	Needs, motivations and challenges	*Design* workshop audio and written records
	Suggested design elements	*Design* and *Evaluate* workshop audio and written records
	Assessment of intervention prototype design by participants	*Evaluate* workshop audio and written records, live online survey during *Evaluate* workshop
ii) Participant's assessment of co-design process and outcome	Participant assessment	Survey after co-design process, *Evaluate* workshop audio and written records
iii) Impact of co-design process on participants	Environmental attitude, home energy system awareness	Differences between survey responses before and after co-design process

3.3. The implementation case study

We applied the above co-design process to a project, run in Switzerland in 2021, aimed at developing and field testing a smartphone app providing smart-meter consumption feedback to support a reduction in household heating and non-heating (i.e., lighting, appliances, etc.) energy demand. We use this project as a case study, in order to both show how the co-design process can be implemented and also to validate the process through the assessment and discussion of its outcomes.

The co-design process was run in three neighbouring regions in German-speaking Switzerland (Schaffhausen, Winterthur, and Wil) between January and July 2021. A sample of 1200 household members was selected as potential target participants for a behavioural intervention and invited by the local energy utilities to join the co-design process. The household members were offered a small incentive for participation, e.g., a gift certificate for local businesses. The co-design process was initiated and guided by our research team, made of behavioural social scientists, energy engineers, design experts and software developers. Domain experts from the local electricity utility companies and an energy data management company were also involved.

Overall, 54 people signed up to participate in the co-design process. Their socio-demographic descriptions are outlined in Fig. 3. The average age of the participants was 53 years old, and they were mostly male homeowners, living in an adult-only household.

The three workshops envisioned by our methodology were held in parallel in each of the three regions, giving nine workshops in total. Separation by region helped build relationships between the participants and allowed a focus on the local context, as the energy delivery and measurement system differed in each region. Also, the small number of participants per workshop (on average, 15 people) allowed more time for each participant to voice their opinions. Of the 54 participants, 45 (83 %) attended at least two of the three workshops. Due to COVID-19 restrictions, all the workshops were held online using a video conferencing platform (Zoom).

We specifically aimed to use co-design to address the challenges outlined in Section 2.2: overcoming the intention-behaviour gap between the MAP phases; ensuring participant engagement (i.e., reducing attrition); and fostering long-term behaviour change. Considering the MAP framework for energy savings [7], the household members were expected to provide insights on what worked for them to save energy at home and what they imagined they would need to progress further. Table 2 outlines exemplary inputs from participants engaged in other co-design processes specifically for energy savings [18,26,28], as an indication of the types of inputs we expected to collect. These inputs are mapped onto the socio-psychological factors associated at each MAP phase following [7].

The co-design process was implemented as follows. The *Discover* workshop ran empathising activities to get the participants familiar with each other and supported the research team in getting to know the energy awareness of the participants. Further, the workshop critically explored other energy savings apps with the aim to identify their strengths and weaknesses. At the end of the workshop, a live online survey tool was used to collect feedback on what could be improved for the next workshops.

The main generative exercise was performed in the *Design* workshop: small groups of five people used generative prototyping [34] to develop stories of how a fictitious user (a persona) in a preaction phase would interact with a new energy savings app. The personas had a specific energy savings goal (i.e. heating, washing or cooking, see Fig. 4) and should move from preaction to postaction through the behavioural

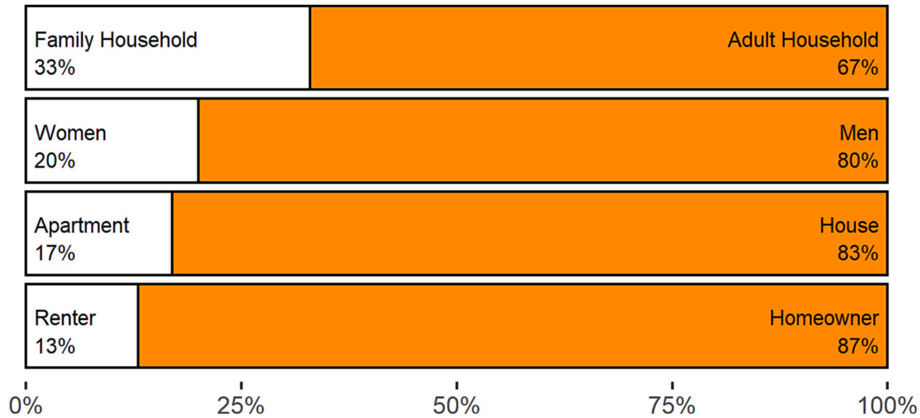

Fig. 3. Descriptive information on characteristics of co-design participants ($N = 54$).

Table 2
Exemplary participant feedback we expected to collect during the co-design process, with respect to socio-psychological factors at each MAP phase.

Behaviour change MAP phase	Socio-psychological factors	Exemplary participant feedback on…
Preaction	Attitudes	• Motivations to save energy and protect the environment/ climate • Concerns to achieving savings in their own homes • Knowledge/perception about their own impact • Influence of social comparison
	Perceived behaviour control	• Their own energy and technology literacy • Reflection on their patterns of consumption
Action	Action planning (Planning skills)	• Knowledge about how to save in their own homes • Feedback on specific saving potentials in their homes
	Coping planning (Solving implementation problems)	• Problems to save energy (real or imagined) • Social interactions (sharing of suggestions and experiences) with other peer households
Postaction	Resisting relapses & dealing with setbacks	• Interactions with other household members • Needs for reminders and additional information

intervention. The personas explicitly reflected the characteristics of the participants, based on the pre-process survey and *Discover* workshop, to elicit what the participants experienced, what helped them, or what they would still need to reach the energy savings goal.

During the *Design* workshop, each small group was invited to create a specific user story about: when and how often the persona would open the app, what information she/he would like to see in the app, which data is interesting and how it should be visualized and contextualized, what the persona would like to do with the data, and how she/he would like to interact with other users of the app. Particularly, when developing a story for the persona trying to reach the particular energy saving goal, each group answered the following questions:

i. Which specific energy behaviour shall be addressed in your user story?
ii. How can the app support behaviour change in this area?
iii. How is the app used by the persona?
iv. What features and information can be found in the app to support the behaviour change?
v. What does interaction with other app users look like?

The groups guided themselves in developing a user story. This was intended to reduce the influence of researchers in the process and enabled more participant-led outcomes. This generative technique helps researchers access deeper knowledge of the participants, as the participants imagine scenarios for a potential user and place themselves in their own created stories [31,34]. Following a presentation of the user stories, the workshop ended with a live online survey asking about preferences for design features [67,68], such as notification frequency, team competitions, goal settings, weekly challenges and gamification elements like points.

A qualitative content analysis [65] of the user stories and live online survey responses was performed by the research team and reviewed by the domain experts to identify design inputs for the app-based intervention prototype. A preliminary intervention design and non-functional app prototype were presented at the final *Evaluate* workshop, during which participants were invited to provide feedback, via small group discussions (max. 7 participants) and a live online survey.

4. Results

4.1. Design contributions of participants to the behaviour change intervention

Participants developed 12 user stories in the *Design* workshop, based on the five different preaction user personas and three energy saving goals provided (as shown in Fig. 4). The stories depict different ways a persona uses an energy feedback app and engages with the accompanying behaviour change intervention to reach an energy savings goal. This uncovers the participants' perceived needs, motivations, and challenges to save energy. From these stories, five design feature categories, containing 16 unique inputs, were extracted (Table 3).

Some inputs can impact multiple MAP phases, thus ultimately eight inputs emerged related to the preaction phase, eight for the action phase, and three for the postaction phase. This is a valuable outcome considering the heterogeneity of future app users. To address the phase of energy saving behaviour in different household domains, the app could incorporate various features to meet people where they are in the process [6].

In the preaction phase (see Table 2 for reference to socio-psychological factors), the participants' emphasis was clearly on increasing perceived behavioural control through detailed energy feedback for more impactful energy saving, and less so on increasing pro-environmental attitudes. Throughout the co-design process, the participants repeatedly requested more individual-level energy use details, energy savings tips, and integration across multiple energy technologies (e.g., data on PV panel production, the load status of an electric vehicle, and interactions between these). This explicit interest in individual, data-driven feedback was further seen in the live online surveys

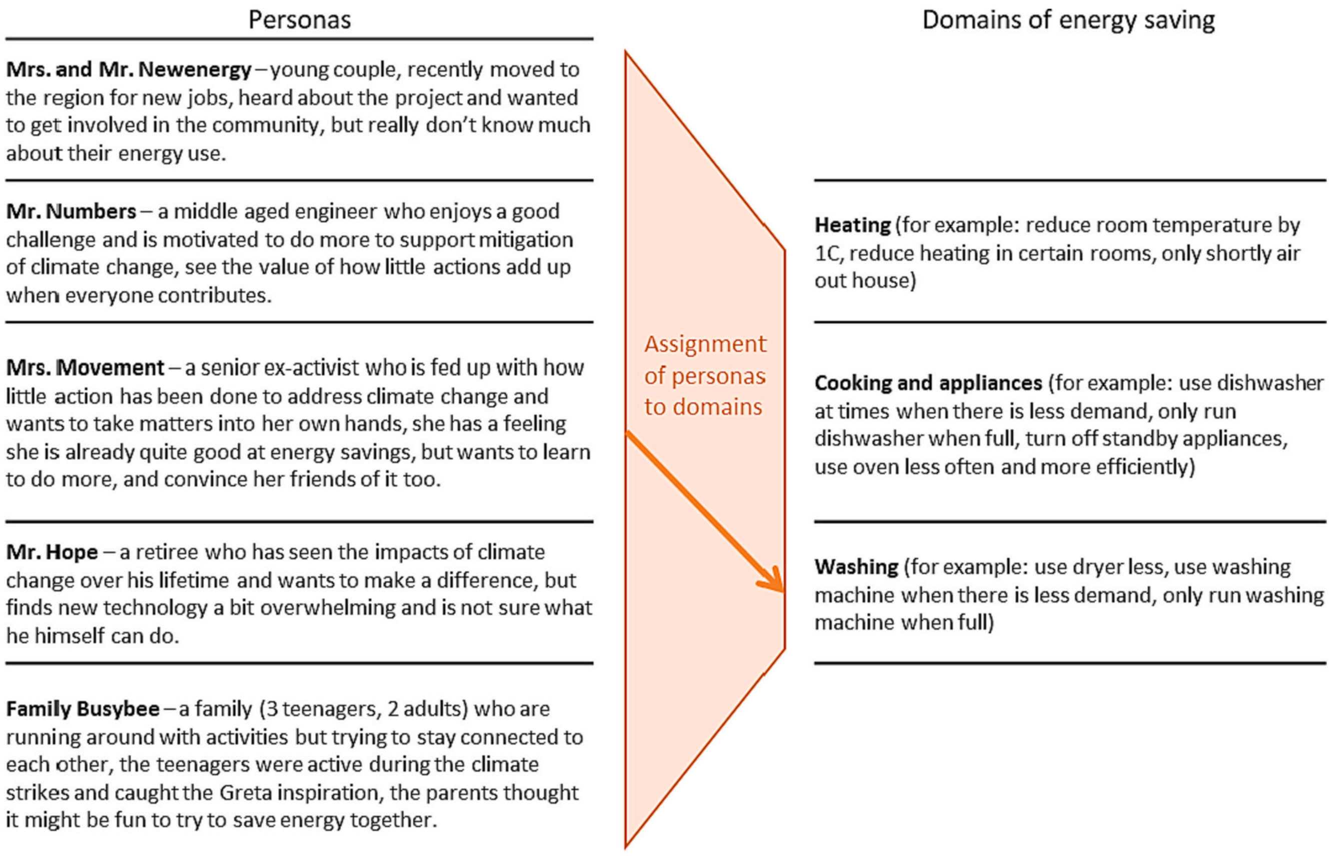

Fig. 4. User personas in a preaction phase and domains of energy saving at home used for the development of user stories.

where participants were asked to rank different app features based on their interest to use them: the predominant interest was in seeing one's own energy saving data, and not in the group-level achievements. Interestingly, the motivational gamification elements (e.g., competing with a team, earning points) were often ranked lowest, especially those related to between-household interaction in teams of participants.

For the action phase, the design inputs strongly aligned with solving implementation problems and reducing the risk of dropouts, as participants suggested to set savings goals and competitions to promote active engagement. As well, they suggested an interaction element, a pinboard, where users could interact with each other. The pinboard could be used to both ask questions and exchange experiences, which is particularly relevant for the postaction phase to provide continued encouragement and address newly arising challenges (e.g., because of seasonal changes). The pinboard could also be used to announce results of a between-regions energy saving challenge, thus reinforcing social norms.

Finally, participants proposed to reinforce the behaviour in the postaction phase through notifications coming from the app to help with resisting relapses. Additionally, they suggested energy consumption data should be available at various disaggregation levels over a longer period to review one's own progress.

The user stories also highlighted the implicit motivation and barriers from the participants' perspectives, which go beyond categorization in the MAP, specifically: how the user should interact with the app, what is the best way to display feedback, what does a team energy savings challenge look like, how can energy savings be achieved, what information should be presented in the app. Importantly, the participants highlighted where potential barriers exist, in terms of digital literacy, convenience, and motivation.

The knowledge transfer from the co-design workshops to our research team was planned directly after the *Design* workshop and included two months for development. The new app prototype and intervention design were presented to the participants as exemplary smartphone mock-ups, which provided a clear visual representation of the main app screens and features (Fig. 5). However, it was not possible for the participants to directly experience the functionality by themselves in an interactive app. Nevertheless, in the *Evaluate* workshop participants could directly provide feedback on usability and additional development possibilities.

The prototype of the app-based intervention presented in the final *Evaluate* workshop integrated the design inputs that were technically feasible and within the resources and scope of the project as identified by the research team and experts (see the last two columns of Table 3). For example, the app prototype included a feature to set an energy saving goal with daily and weekly feedback on progress towards the goal. Also, the prototype incorporated an approach for users to self-report appliance use in the app to match it to electricity consumption peaks. Many of the ideas were original and had never been implemented in previous apps developed by our teams (e.g. to have competitions within a household or to display the environmental impact of energy consumption) while others improved ideas we had already explored in a similar app-based behavioural intervention [51,69] (e.g. using stoplight colouring to quickly and easily indicate progress). Overall, the design of the app and the related behaviour change intervention directly incorporated many of the participants' ideas.

The final design was a compromise of all the inputs from the participants and technical and resource limitations in the project. This natural limit to the extent that participants could influence the final design was communicated at the start of the co-design process.

4.2. Participant's assessment of co-design outcome and process

The main outcome of the co-design process was the app-based intervention prototype. The participants gave a positive evaluation of

Table 3
Design inputs from user stories for the app-based intervention.

Design feature	Inputs from participants' user stories	MAP phase	Features included in intervention and app prototype presented in *Evaluate* workshop	Decision by research team & experts
Energy data feedback	Feedback on environmental impact of own energy consumption	Preaction	Not included	This feature was not implemented due to the diversity of environmental impacts associated to different energy sources.
	Comparison of savings to similar households	Preaction	Heating and non-heating energy consumption of similar households.	Households grouped (families, adults < 65 years old, adults > 65 years old) and average consumption data is shown for their category.
	Energy efficiency rating of household and appliances	Preaction	Not included	Outside of project scope because of technical complexity and resource intensity to get sufficient accuracy on heterogeneous appliances.
	Energy consumption data can be viewed at different disaggregation levels and time scales	Preaction Postaction	One section is dedicated to visualizing energy consumption data (bar charts) by hour, week and over the whole project, as well as for heating, non-heating uses, and total energy consumption.	Participants envisioned a more interactive interface where charts could be dynamic (zoomed-in for additional time scales, etc.). However, this was outside the technical resources of the project.
	Individual goal setting (energy saving) and feedback on progress towards goal	Action	Individual goal setting for both heating and non-heating energy consumption. Charts and feedback on the daily and weekly progress.	Goal setting performed at start and can be modified at any time.
	Integration of other household energy data, such as self-production (e.g., installed PV) or electric vehicle charging	Action	Not included	Outside of project scope because of technical complexity to integrate additional energy data interfaces, which may be proprietary, or more advanced disaggregation algorithms.
	Attractive and easy-to-understand visuals for sharing with others	Action	On home screen: intuitive visual representations of energy consumption and goal achievement using stoplight colouring. As well as comparison with similar households.	Features for sharing over social media were not included.
Energy saving challenges	In-app competition with others, including within the household	Action	Monthly energy saving competition between the three regions using the app.	The competition between regions compares the average energy savings of each region for one week to see which region saves the most. No explicit within-household challenges were introduced, since assessing an individual person's contribution was not technically possible.
	Prompt energy savings actions in different areas of the home	Action	Overall, 21 individual energy saving challenges, focusing on 8 household energy consuming areas (heating, showering, washing, cleaning, cooking, dishwashing, studying and working, recreation).	Challenges incentivize actions to be taken at home, and completion is not quantitatively assessed by the amount of energy saved, as this is technically feasible with the disaggregation possibilities. Instead, to fulfil a challenge the user must share about their experience, problems, and solutions in the Pinboard.
User inputs	Customised notification frequency and timing (e.g., lunchtime savings tips every day at 11 a.m.)	Action Postaction	Automatic notifications sent by the app at pre-defined times.	In the context of the limited resources available for development of the app, implementation of the suggested feature was not possible.
	Track energy use-relevant activities (e.g., doing laundry or having visitors for dinner) to see impact on energy consumption	Preaction	On a daily calendar, users can manually add an activity at a specific time. Such memos can then be compared with the chart showing hourly consumption data.	The energy diary feature was included in the app prototype, but it could not be included in the final app version, since other features were given priority in software development and resources were not sufficient to include all the prototype features.

the prototype app design in the *Evaluate* workshop and in the post-process survey (Fig. 6). Overall, the participants liked the prototype design, but did not expect the app to be interesting for their close social network (i.e., others in their household or their friends). During the workshop, many participants remarked that their friends would either not meet the requirements for app use (lack of metering infrastructure or living in multi-storey apartments) or would not have sufficient interest and willingness to invest time into energy saving activities. Seemingly, their social network is not in a preaction phase, but rather in the prior predecision phase, which may reveal a weakness in the potential of social influence on energy savings (for the positive influence, see for example [70,71]).

In an open question, participants described what elements they thought were still missing from the prototype design, namely more automated data collection and highly disaggregated energy consumption feedback on appliance-specific energy use. We found these missing elements relate broadly to a preaction desire for more perceived behavioural control. As well, participants desired summaries of different energy use impacts (e.g., lighting, cooking, temperature-corrected heating consumption, ecological footprint), gamification (e.g. earning

Design feature	Inputs from participants' user stories	MAP phase	Features included in intervention and app prototype presented in *Evaluate* workshop	Decision by research team & experts
Customised recommendations	Energy saving recommendations based on analysis of appliance consumption data	Preaction	Overall, 90 general energy saving tips, covering the 8 challenge topics (heating, showering, washing, cleaning, cooking, dishwashing, studying and working, recreation) were added in the app and rated on three point scale along their energy saving potential. However, no personalised tips were implemented.	Offering customised energy saving recommendations, also accounting for external conditions such as the weather or using location features, would require a dedicated project aimed at automatically analysing, disaggregating and comparing energy consumption data against a benchmark and/or other automatically collected data (mobility, weather). This was outside the scope of the project.
	Location tracking to recommend heating regime (e.g., less heating when people not at home)	Preaction	Not included	
	Tips based on weather (e.g., plan laundry tomorrow to use sun for drying)	Action	Not included	
Exchange with other participants	Pinboard for user posts with thread function	Preaction Postaction	Pinboards for each of the challenge topics (resulting in over 20 unique pinboards) were created.	An internal "Pinboard" for posting messages (e.g., questions, feedback, suggestions) to all users and the research team was included. This is supposed to favour greater interaction within the app users. Thread function was not technically feasible within the resources of the project.
	Pinboard with entertaining functions like emoticons or pictures	Action	The pinboard allows for picture uploads.	Emoticons could not be provided due to technical restrictions of the app design.

points), and expressive elements (like gifs, emojis). Although the gamification and expressive elements had been previously dismissed in the participant's user stories as rather unnecessary, in the *Evaluate* workshop they were seen as potentially useful to add. These elements are shown to support motivation and engagement [72].

Concerning the assessment of the co-design process, in an open question in the post-process survey the participants provided their reasoning for why they thought this process is useful for the design of a smartphone app. There were three main reasons: a user-oriented approach is better when developing something for someone else; more opinions will make a more relevant and effective product; including non-experts provides real world experience to improve the design. This mirrors current discussions on the positive value of collaboration and transdisciplinary research for energy transitions [73].

Additionally, in the post-process survey participants rated their experience of the workshops with respect to the principles of collaboration on transparency, integration and accountability [30]. Overall, participants responded very positively, with scores over 3 representing a positive response (Fig. 7).

The co-design process was positively assessed by the majority of participants. A direct indicator of such a positive assessment is also related to the low drop-out rate: of the 54 registered participants, 45 participated in at least two workshops, and 30 participated in all three. While the process appears to have been acceptable to the participants, the overall effort needed from their side also appears to be reasonable, as 61 % of the 41 responding participants declared they would certainly join a co-design process again, 39 % would maybe join, and none were against joining.

4.3. Impact of co-design process on participants

Recruitment aimed at people who were already intrinsically motivated to save energy but were not sure where to start or how to make an impact. To get insights on their actual motivation, in the pre-process survey participants were asked to rate their reasons to participate in the co-design process on a scale of 1 (not a reason to participate) to 5 (very much a reason to participate), as reported in Fig. 8.

These motivations were further reflected in the questions and inputs of participants during the workshops. Overall, by accounting for the survey answers and the interaction in workshops, three main motivations appear: a) *technological curiosity* – being interested in learning more about energy technologies such as optimizing photovoltaic panels and electric vehicle charging; b) *energy saving* – wanting to learn how to save (more) energy and possibly also save money in doing so; and c) *climate relevance* – wanting to do more to address climate change. These motivations highlight the participants' intrinsic motivation for energy saving (i.e., preaction and action) and showed their interest and openness to change.

Questions on participants' awareness of how their water is heated at home and how their smart meter works were included in the two online surveys performed before and after the co-design process (Table 4). A within-subjects *t*-test indicated that smart meter awareness significantly increased during the co-design process (M difference $= 0.42$, SD difference $= 0.79$, $t\ (37) = -3.27$, $p = 0.002$, Hedges $g_{av} = 0.43$) wherein the common language (CL) effect size indicates the likelihood of this change to be 70 % [74]. Whereas knowledge about how water is heated did not significantly change, the participants perceive themselves as more knowledgeable about their water heating system than their smart meters.

Additionally, in the pre- and post-process surveys, energy consumption attitudes [66] were measured along several variables (Table 5). Despite a small decrease in the items in the post-survey (non-significant in all but one item), in both surveys scores all are above the midpoint of the scale, that is 3, showing generally high pro-environmental attitudes. One exception is a significant decrease in the interest to "do more to save energy if I knew how" (M difference =

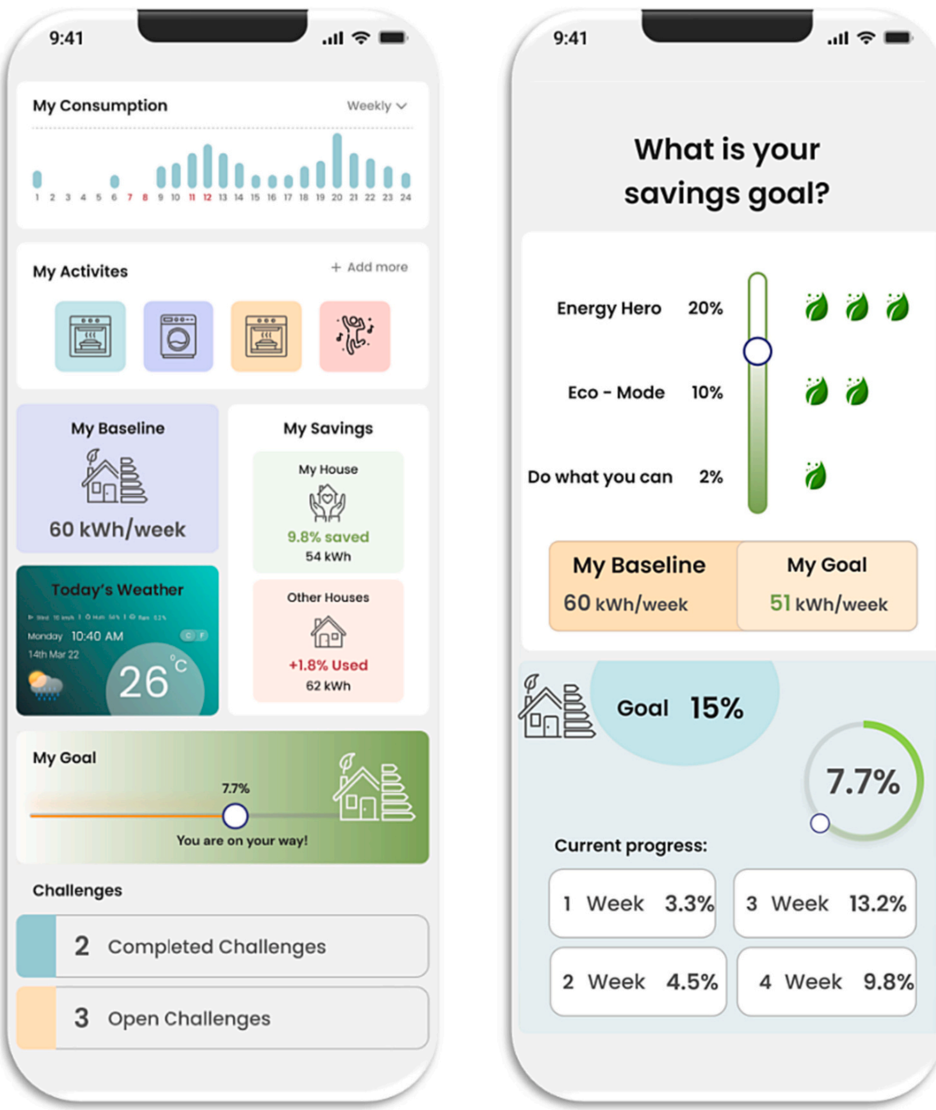

Fig. 5. Exemplary non-functional prototype of the co-designed energy savings app (left: home screen, right: goal setting screen).

−0.40, *SD* difference = 0.95, t (37) = 2.57, p = 0.014, Hedges g_{av} = 0.32), although the mean scores are still above the middle score of 3 (*M* pre = 3.66, *M* post = 3.26). The CL effect size indicates the likelihood of this decrease to be 66 % [74]. Note that a decrease in such an item could also be explained as an increase in knowing how to save energy, as a consequence of participating in the co-design process.

5. Discussion

The above analyses attempt to assess the co-design process we envisioned to provide specific inputs to a behavioural intervention based on the MAP framework. We explored the potential use and effect of the outlined co-design process for generating new design ideas to ultimately improve the impact of an intervention.

Specifically to the intention-behaviour gap, co-design uncovers different underlying factors, including unconscious habits [75], and considers the broader context of behaviour change beyond intentions alone [6]. For the implementation case, co-design activities allowed space for the participants to reflect, imagine, and contribute to our understanding of what stands between the preaction, action and postaction phase in terms of practical and real-world barriers, which may have been missed by a strictly theory-driven approach. Further, as participant attrition and behavioural maintenance after the intervention is context dependent [15,16], the user stories and workshop discussions highlighted how intervention design could be improved, e.g. by providing smartphone notifications at relevant times before the behaviour takes place or by allowing user interaction via the pinboard, to enhance the feeling of a supportive community towards a common goal.

Overall, the co-design process informed decisions beyond best-practices from literature and incorporated local needs and current interests in the topic of energy saving. Through the user stories and feedback of participants, the design addressed the persisting issues of low engagement in behavioural interventions, lack of embeddedness in the user's real-world context, as well as developed approaches to support long term maintenance of the desired behaviour. Through real-world testing of the app, being carried out in a separate study, we will be able to conclude on the effectiveness of co-design to reduce these problems.

5.1. Reflections on co-design process

The participants served as novel sources of inspiration for our experienced app development team (Table 3). However, we had to balance the limited feasibility of some of the inputs within the predefined scope of the project, as well as acknowledge the participants' limited experience with designing for behaviour change. While the

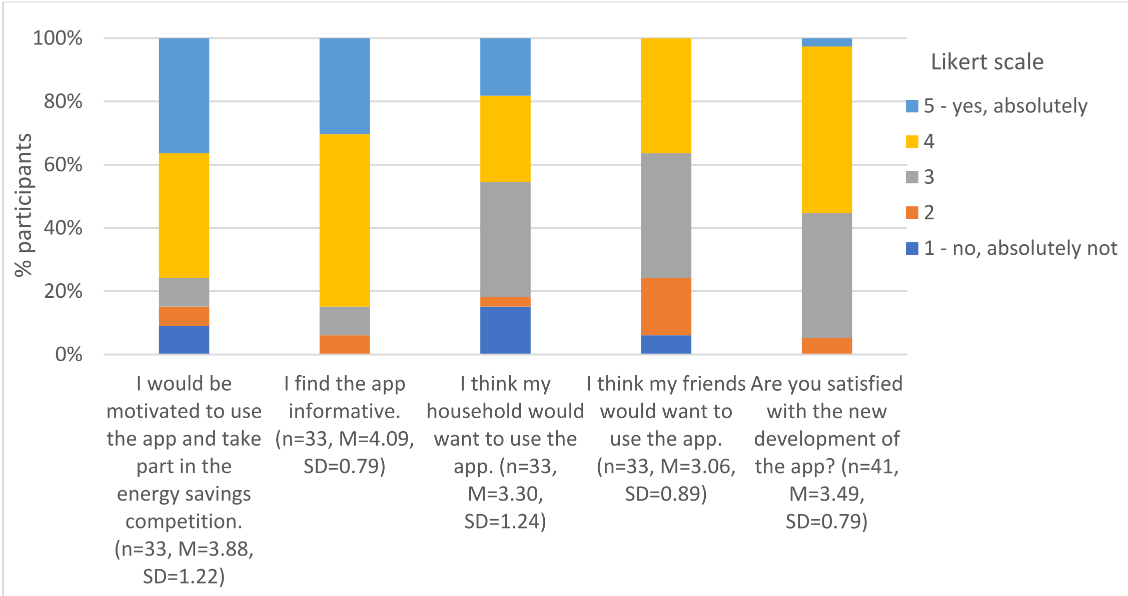

Fig. 6. Assessment of prototype app design. Each statement/question is followed by the number of responses (n), response mean (M) and standard deviation (SD).

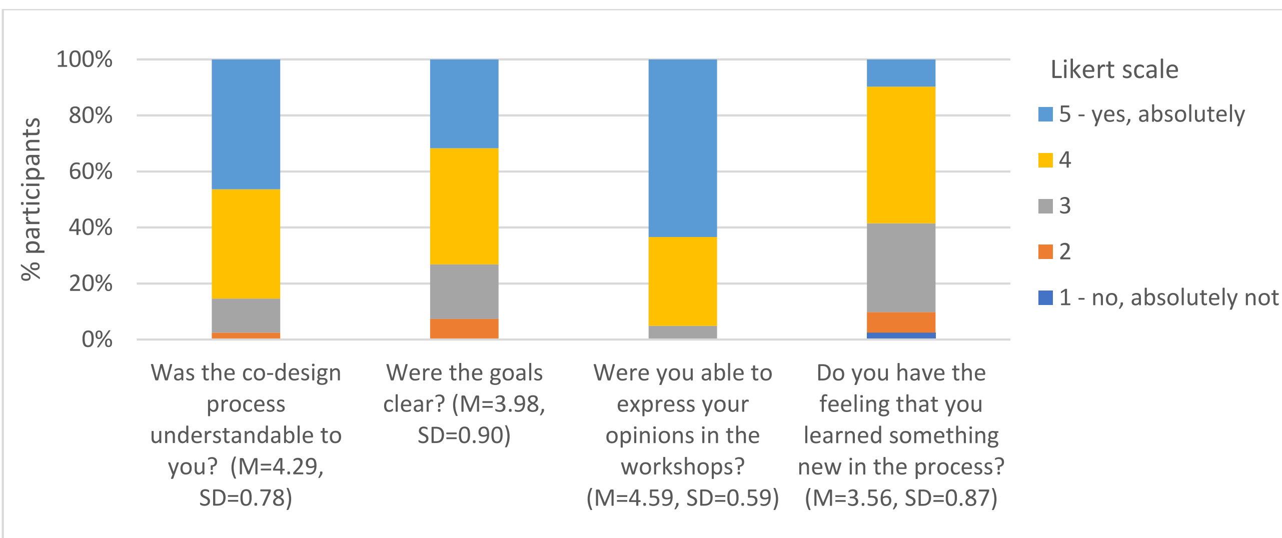

Fig. 7. Assessment of the co-design process. Each survey question is followed by the response mean (M) and standard deviation (SD). $N = 41$ for all questions.

participants felt that their opinions mattered and were heard, it was important to keep expectations realistic that not all feedback could be incorporated and that the final app and intervention design would not be the only result of their proposals.

For example, during the workshops, it became apparent that the participants were less interested in the motivational gamification elements and preferred instead to have more data and direct feedback on their own behaviour. This input primarily enhances perceived behavioural control at the preaction phase, and thus we chose to additionally address attitude in the prototype design to consider both of these socio-psychological factors in the MAP framework. Thus, taking a wider audience into consideration, gamified motivational features were included in the app (e.g., individual challenges and a between-groups energy saving competition), along with the requested individual-level behavioural and energy use feedback.

Additional to the single design inputs, the user stories also provided a rich picture of participant priorities. We used the motivations and barriers mentioned by the participants to guide decision-making during the design. For example, the intervention resulted in less focus on competition, earning points, or reaching a predefined goal, than initially envisioned by the research team. This was a critical decision for us considering the hypothesis that individual behaviour change may be motivated by the awareness of social norms [76], e.g. knowledge that others are also acting in alignment with the same goal. However, this type of reflexivity on research is intrinsic to co-design and achieving more transformational impact [73]. Thus, the prototype and the intervention now focus more on exchange and support between users, and the ability to set their own individual saving goal.

Overall, this abductive process trained reflexivity in the research team, that is an increased awareness of assumptions and role in decision-making, which is an expected outcome of co-design [58].

5.2. Reflections on co-design participants

The socio-demographic indicators reported in Fig. 3 show that the participants are not representative of the general Swiss population in

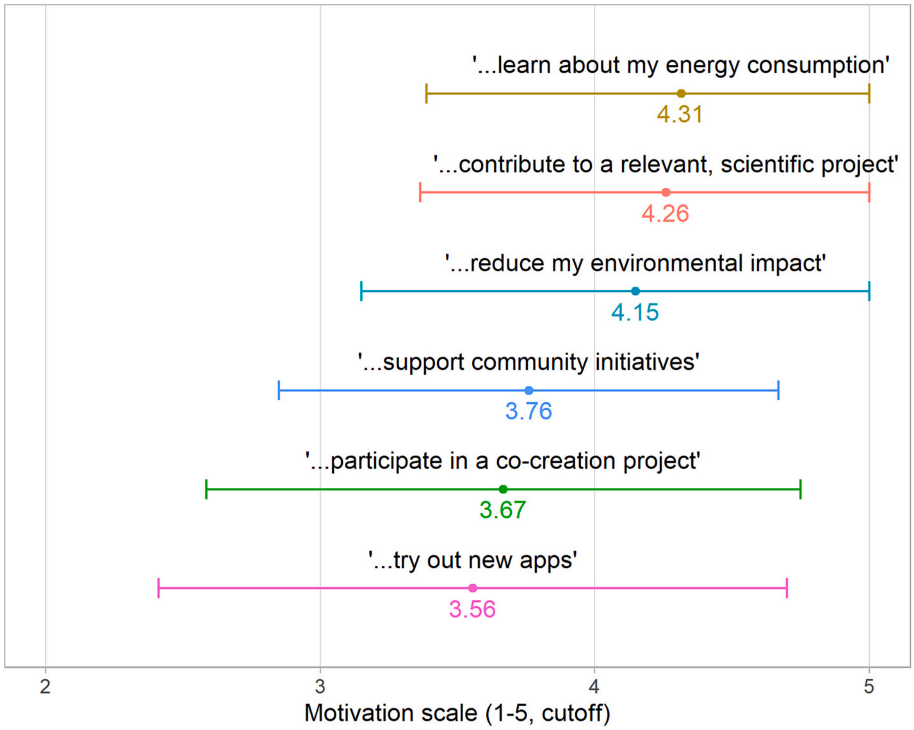

Fig. 8. Rating of different motivations to participate in the co-design process showing mean and standard deviation bars.

Table 4
Home energy system awareness before and after the co-design process.

Question	Pre-process M (SD)	Post-process M (SD)	Difference $M_{post-pre}$ (SD)	Significance *p*
How much do you know about how your water is heated?	3.61 (0.64)	3.63 (0.59)	0.02 (0.49)	0.744
How much do you know about how your smart meter works?	2.47 (1.03)	2.89 (0.83)	0.42 (0.79)	0.002

n = 38 for all questions; 4-point Likert scale: 1- Absolutely nothing, I have no idea; 4- I have a good idea of how it works.

Table 5
Environmental attitudes before and after the co-design process.

Statement	Pre-process M (SD)	Post-process M (SD)	Difference $M_{post-pre}$ (SD)	Significance *p*
The way I personally use energy really makes a difference to the energy problems that face our nation.	3.68 (1.07)	3.42 (1.24)	−0.26 (1.22)	0.193
I would do more to save energy if I knew how.	3.66 (1.17)	3.26 (1.29)	−0.40 (0.95)	0.014
We have to worry about conserving energy, because new technologies will not solve the energy problems for future generations.	4.34 (1.02)	4.18 (0.98)	−0.16 (1.15)	0.403
I believe that I can contribute to solving the energy problems by making appropriate energy-related choices and actions.	4.13 (0.91)	4.08 (0.88)	−0.05 (1.09)	0.767
I believe that I can contribute to solving energy problems by working with others.	3.95 (1.01)	3.84 (1.05)	−0.11 (0.92)	0.487

n = 38 for all statements; 5-point Likert scale: 1- I do not agree; 5- I fully agree.

terms of their age (Swiss average 43 years old vs. 53 in sample), gender (Swiss average 50 % men vs. 80 % men in sample), house type (Swiss average 18 % (semi-) detached house vs. 83 % in sample), and house ownership (Swiss average 36 % owner vs. 87 % in sample) [77,78]. However, representativeness was neither expected nor the aim. Instead, participants should reflect the intended behaviour change population, and thus in the implementation case we recruited household energy consumers with a similar energy infrastructure as would be needed for participation in the future app-based intervention: that is, they live in a (semi-) detached house with their own electrical or gas heating system.

The requirement for a (semi-) detached house is related to house ownership, which is rare in Switzerland at only 36 % of homes being privately owned, and thus the lowest in Europe (compared, for example, to 65 % in the UK and 51 % in Germany [79]). Thus, it is not surprising, that the average age of participants is quite high, as many people in Switzerland can only afford a house later in life. The predominance of men in the participant group is not surprising either, as affinity and self-efficacy for energy and technology-related topics tend to be more prevalent in men [80,81], thus more men will participate in such processes if recruitment does not explicitly aim for a gender balance [82].

Furthermore, the participants are likely not representative of the general population from the perspective of their phase of behaviour change to save energy. The app is intended for people who are at the preaction stage of energy savings, i.e., they want to reduce the impacts of their energy consumption but are missing the necessary information, knowledge and competencies (perceived behavioural control), or the last push to act (attitudes). It was apparent that the incentives to participate in the co-design process aligned with the participants' relatively high energy awareness and knowledge (see Table 5). As the household participants were voluntarily recruited with only a small incentive (i.e., a gift certificate) for participation, their intrinsic motivation was necessarily high from the start. For instance, in the online survey at the end of the *Discover* workshop, one participant mentioned that the group was made up of the "highly motivated".

The aim of the workshops was not to necessarily change participants' behaviour, and this seems to be the case for the measured awareness and attitude items in the before and after survey. Considering the participant's high motivation and stated knowledge around energy issues, a large shift in their attitudes was not expected, as there was little potential left to increase it. In fact, the co-design process did not have a measurable impact on the energy awareness of the participants.

The participants' high intrinsic motivation could question whether they were the right participants for the design of an app for a less motivated audience. To address this, the personas we used to develop the user stories were inspired from the characteristics of the real participants, albeit set in the preaction phase. Participants were instructed to imagine the experience of a future app user from this perspective, therein we assumed that a future user would be similar to the co-design participants. The post-process survey response provided an additional perspective on future users: the participants did not expect their close network would be interested in the app and intervention. Thus co-design can provide insights for future design, but will not necessarily capture the entire potential intervention audience.

The participants' high motivation might have also affected the design results of the app. Namely, the app may have limited appeal for people with different attitudes and motivations, e.g., young people or uninterested and unexperienced homeowners. Nonetheless, the self-selected co-design participants are likely comparable with those that later on will self-select to join the app-based energy savings intervention, which will also be voluntary to join.

It is to be expected that voluntary behaviour change will attract those already interested in addressing the impacts of their behaviour. This is unlikely to change without wider social movements or policy measures which change attitudes. For the energy transition, this will mean that people who will participate (in co-design or in an intervention) are already more aware of the relevance of energy consumption and are motivated to change. Amongst the case study participants, the three main motivators to participate (i.e., technological curiosity, energy saving, and climate relevance) provide some indication on how the energy savings app and project are perceived from the outside, despite this set of participants being particularly energy affine. For future intervention co-design, dedicated efforts should be made to attract more diverse participants who may have other non-energy related interests to participate in a co-design process (e.g., curiosity about an app development process).

Through empowering citizens and supporting a sense of community, co-design processes are argued to have an effect on democratizing societal processes [23], which is certainly more likely if participants are happy with the process they experienced. In this sense we hope that our efforts with co-design might have also contributed to a more participative society – even if only to a very small extent.

6. Conclusion

This paper presents a co-design process we developed to complement theory-based behaviour change interventions. Particularly, we chose the MAP framework which supports users to progress wherever they are in the behaviour change phases. To show how co-design works in practice and assess its effectiveness, we refer to an implementation case study, aimed at co-designing a smartphone app-based behaviour change intervention to save energy. The experience we gained from this case shows that, ultimately, a co-design process captures relevant user insights that can assist researchers in designing better interventions that feel more personal, contextual, and achievable. Despite the undeniable extra effort of the process, the design insights proved to be original, informative, and feasible for our research team, and well-fitting into the MAP framework. Future intervention designs may profit from incorporating aspects of co-design to complement theory, support a more theory-driven design process, challenge assumptions, foster new ideas, and address contextual motivations.

However, it is a challenge to find the balance between open and creative discussions and a guided process to fulfil the goals of the research project. This challenge characterises any collaborative process, and thus the scope for inputs must be clearly defined to remain within the financial, temporal, and competence constraints of a project. Most importantly, this scope has to be communicated from the very beginning to the participants to effectively manage expectations.

Work on achieving individual behaviour change will necessarily continue to contribute to national energy goals and climate agreements [1]. Collaborative approaches, such as co-design, offer an approach to integrate local realities with prior research findings. The co-design process presented has proven to be a valuable complement to theory, from both the viewpoints of the research team and the involved participants. Future implementation of the app and intervention in the field trial will prove if the outcome of such a highly resource- and time-intensive co-design process will be beneficial in terms of a more enduring and higher energy-saving impact of the intervention.

Ethics approval and consent to participate

The study presented in this paper was approved by the Research Ethics Committee of the Zurich University of Applied Sciences. Participants to the study were informed in advance of participation of the data that was to be collected, how it would be stored and analysed, and their rights for withdraw. Written consent was given by all participants upon registration.

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CRediT authorship contribution statement

DW: conceptualisation, methodology, validation, data curation, formal analysis, writing; EL-K: methodology, investigation, data curation, writing; SJ: investigation, data curation, writing; FC: writing, project administration, funding acquisition. All authors read and approved the final manuscript.

Declaration of competing interest

The authors declare that they have no known competing interests that could have appeared to influence the work reported in this paper.

Data availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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