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Authors

Dressa, Matthew

Hassani, Maryam

Epstein, Daniel A

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Whose Carbon Is It Anyway? Exploring Household Dynamics in Sustainable Mobility Tracking

MATTHEW DRESSA, University of California Irvine, United States
MARYAM HASSANI, University of California Irvine, United States
DANIEL A. EPSTEIN, University of California Irvine, United States

Transport behaviors are a major contributor to carbon emissions, and decisions are often made at the household level around what form of transport to take and when. Technology, primarily eco-feedback interfaces (EFIs) have been suggested to support users in making environmentally friendly choices. However, there is a lack in understanding of how the underlying social dynamics of households influence decisions around sustainable practices, particularly through the lens of mobility. To understand how to design technology to better support households in negotiating around sustainable mobility choices, the research team interviewed 21 participants across nine households, probing them with four low-fidelity mockups representative of EFIs from prior work. We found that the varied mobility-related responsibilities among household members, as well as varying perspectives on the environment, can cause friction in the utility of EFIs in the home. We suggest that designs can account for these factors through acknowledging varied roles and perspectives.

CCS Concepts: • **Human-centered computing → Empirical studies in HCI**; **Empirical studies in collaborative and social computing**.

Additional Key Words and Phrases: Sustainability, HCI, Transportation, Eco-Feedback Interface

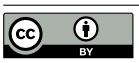
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1 Introduction

The increasing urgency of the global climate crisis is undeniable, as evidenced by the proliferation of extreme weather events, rising sea levels, and widespread environmental degradation [12, 116, 130]. Mobility and transportation is an important contributor to climate change. As of 2022, it is estimated that nearly 28% of greenhouse gas emissions in the United States is a result of the Transportation sector, and approximately 94% of this consists of petroleum, non-renewable, fuel sources. If this trend continues, it could have more severe negative impacts on our environment [125]. To ameliorate this difficulty in unsustainable transportation behaviors, many stakeholders across different sectors have advocated for more sustainable practices, such as adoption of electric vehicles and the construction of infrastructure for diversified methods of transport (e.g., biking, trams, buses) [126].

In response to sustainability concerns, the field of Sustainable Human-Computer Interaction (SHCI) has historically turned its attention to developing tools and systems that encourage individuals to understand and adapt their less-sustainable practices. Many systems take the form of

Authors' Contact Information: Matthew Dressa, Informatics, University of California Irvine, Irvine, California, United States, mdressa@uci.edu; Maryam Hassani, Informatics, University of California Irvine, Irvine, California, United States, mhassan2@uci.edu; Daniel A. Epstein, Informatics, University of California Irvine, Irvine, California, United States, epstein@ics.uci.edu.



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eco-feedback interfaces (EFIs) [29], which are systems designed to provide users with visualizations of their environmental impact. EFIs can be implemented to show impact across various domains, such as transportation [27, 86], food waste management [120], and home energy consumption [54, 134]. Eco-feedback interfaces have traditionally been studied at the level of the individual [31, 41], focusing on how personal data can encourage reflection and support behavior change. However, sustainable practices are often negotiated through social groups, such as households, where decisions are rarely made in isolation and resource use is shared [46, 104, 117]. For example, a household having young children can introduce transport responsibilities like school drop-offs or extracurriculars, while also limiting transit choices to maximize safety and minimize travel distance [71]. Moreover, by examining how EFI systems are utilized in social contexts, we might better understand what shared responsibilities, interdependencies, and collaborative strategies exist within homes that shape sustainable practices and how we can support these collaborative properties through technology. We therefore address the research question, *How can the design of EFIs account for the dynamics and social structures in households to better promote sustainable mobility practices?*

We use the term "household" to encompass a range of living arrangements, including nuclear families, multi-generational households, and roommate arrangements. Household arrangements worldwide are evolving due to rising divorces, declining birth rates, and shifting economic pressures, moving young adults to increasingly live with relatives or non-family members for financial reasons [2, 15, 26, 47, 101]. The use of "household" overlaps with the more typical HCI focus on understanding and supporting the practices of families (e.g., [50, 89, 94, 111]), but also introduces more nuanced, and potentially complicated, social relationships around sustainability decisions. While previous research has explored sustainable practices through the lens of domestic consumption (e.g., food waste, electricity) both between [21] and within [85] 'non-traditional' households, there is a gap in understanding the impact of these social dynamics in the context of sustainable mobility.

In our study, we explored our research question by conducting focus group interviews with 21 participants across nine households to better understand how their dynamics impact sustainable mobility decision-making, and receive feedback on four low-fidelity mockups which were representative of the design space from prior work in EFIs for mobility [4, 29, 138]. We found that household members had different roles or tasks related to mobility within the home, which raised concerns related to how their data would be attributed or aggregated. In addition to roles, participants highlighted that EFIs could struggle to account for divergences in environmental concerns, where some household members were deeply invested in sustainable practices while others felt indifferent. Lastly, household members indicated that they had different representational needs based on their roles and typical transit practices, which influenced their perspectives on the usefulness of the designs presented to them.

In our discussion, we synthesize our findings through the lens of ethics of care [34, 122] to articulate strategies and tensions to designing EFIs to promote sustainable practices at the level of households. Moreover, through this perspective, we describe how providing conversation scaffolding, through prompts, enables households to reshape their individual and collective definitions around sustainable transit practices. Furthermore, we discuss how features like data annotation, when viewed through an ethics of care lens, can make the inequitable labor of household responsibilities more visible and negotiable. Finally, if EFIs leverage mobility limits or budgets in a household EFI, they may be afforded the opportunity to reflect around their broader sustainable mobility behaviors and goals.

Thus our contribution is twofold. First, we use ethics of care to diagnose why current EFI designs often fail in household contexts and how they can inadvertently reinforce inequities around care work. Second, we demonstrate how the design patterns of Personal Informatic systems (PI) can be

re-appropriated to support the social negotiations of sustainable practices in household life, while also making care work more visible and actionable.

2 Related Work

We first provide a background of mobility work in HCI and how people in homes make transit decisions. We then discuss how eco-feedback interfaces fit within the context of personal tracking and Sustainable HCI research.

2.1 Overview of Mobility in Households

Much of the foundational work in HCI and mobility has primarily focused on technological methods to support alternatives to driving, such as improved experiences in cycling [91], the use of public transit [139], adoption of lightweight vehicles like scooters [123], or mobility futures like self-driving vehicles [84] and Urban Air Mobility vehicles [72]. As ridesharing through companies like Uber and Lyft have become more ubiquitous in daily life, researchers started to examine the socio-technological implications of such systems [67, 75, 118]. For example Mohanty et al. explored the motivating factors for choosing sustainable ride-sharing services, identifying that point-based reward systems and emissions data accrued per ride can be incentivizing [75].

Household mobility requires making sense of an ecology of behaviors and routines accounting for various social, geographic, and economic factors. For example, households with higher incomes are more likely to own cars [49, 80] whereas lower income households are likely to live on the outskirts of urban areas [53], subsequently have longer commutes [43, 107], and less likely to make use of alternative types of transportation [92]. The presence of children further influences how people within households decide on how to move about. When children are young, parents, mostly mothers, are typically responsible for getting children to and from school and other extracurricular activities [46, 71]. Moreover, the literature suggests that built environment factors such as pedestrian safety, proper lighting, and distance, all influence individual children's mobility [104]. As children age, they become more autonomous, such as getting a driver's license or taking public transit on their own, they engage in activities without the need of parents to support their mobility patterns. As a result, households with older children become more flexible in their transportation patterns, making use of a broader ecology of modes of mobility [103]. Some research has also explored the experiences of households that have challenged the car norm. For instance, Hasselqvist et al. conducted a long-term study with families who had given up their cars, identifying how technology could support their new, multi-modal transportation practices [44]. In the context of the U.S., the country, with exception to urban environments, is broadly characterized by high rates of personal vehicle ownership and sprawling, car-centric infrastructure which has created a strong culture of car dependency where alternative forms of transit, such as public transportation, are often not an accessible nor sustainable option for many individuals [62, 126].

To better understand household transit decisions, it is useful to distinguish between two lenses of sustainable mobility planning. Daily planning is characterized by the constant negotiations required to manage day-to-day household travel constraints, such as coordinating errands while managing the array of schedules that exist within and around the home [99]. In contrast, vehicular planning involves infrequent, but high-impact decisions regarding mobility, such as purchasing an electric vehicle (EV), investing in an e-bike, where the primary aim is to support people in developing sustainable mobility preferences based on the financial and energy costs. While a body of work has explored the design of EFIs for making more sustainable vehicular choices [96, 97], the day-to-day challenges of integrating these choices into household life are less explored, representing an important area for investigation.

2.2 Tracking and Coordination in Household Settings

Personal Informatics (PI) consider systems that afford users to track and reflect on their personal data [7] in varied domains such as physical fitness, mental health, dietary monitoring, and social interaction [24]. The most widely studied goal for using PI systems is promoting behavior change [24], which is often the goal of using PI in the domain of sustainability.

Although much of the PI literature is positioned in reference to specific individuals, more recent work has sought to understand how peoples' practices of collecting data, reflecting on it, and acting in accordance are influenced by social and household contexts. For example, researchers have aimed to understand how people in family settings engage with collective data [5, 88, 94, 112, 133]. These previous studies illustrate that tracking in families introduces invisible work for parents, such as keeping devices charged or data up-to-date [81]. Others highlight how different family members might not equally participate in tracking or acting on tracked data [89]. Although these works surface barriers in tracking in these various domains, they provide less insight into the social properties, exchanges, or challenges that exist when tracking jointly within broader living arrangements such as households, and particularly related to sustainability.

Personal Informatics has had a limited focus on sustainability [29, 33, 115]. Moreover, these studies have largely aimed to support sustainability tracking at the individual level. In this study, perspectives on PI systems in households offer a glimpse into when, why, and how people engage and disengage. They emphasize reflection and self identification of and with data, and they also help explain the circumstances where people make sense of data collaboratively [90].

Coordination has been long studied across disciplines such as sociology, organizational theory, and HCI as a critical component of shared life in multi-member households [70]. An increasing body of work in CSCW has sought to examine the cross-sections of technology and a larger variety of household compositions typically viewed as 'non-traditional' family dynamics in Western contexts. For example, prior work has explored how computer technology can support intergenerational family eating practices [82], remote semi-synchronous communication [119], as well as fostering intergenerational connections over large geographic distances through social play [135]. Recent work in the community has also shed light on how technology can support co-parenting methods for divorced parents [23] and family planning for parents with demanding careers [137]. In addition, prior work has advanced our understanding of sustainable domestic electricity monitoring between households in an apartment building complex [21]. Thus, it is clear that apart from shifting demographic changes in family structures, both recent and formative work in CSCW has sought to move beyond 'typical' ideas of household structures and towards more nuanced understandings of how the composition of these groups influence the social connections and responsibilities within the home. The literature also demonstrates that the topic of social dynamics and sustainable mobility decision making within, as opposed to between, homes still remains an understudied area of research.

In the context of sustainable mobility, household coordination is particularly important as transportation decisions often involve multiple stakeholders, such as arranging school drop-offs, sharing vehicles, or joint grocery trips. These activities require ongoing negotiation and communication, both within and beyond the household. *Ethics of care* provides a useful framework for understanding how activities in the home are carried out [34, 122]. In introducing ethics of care, Carol Gilligan brought attention to how the lived experiences between the genders are undoubtedly unequal, the author explaining how women were often burdened with needing to balance their corporate work lives and home care responsibilities tending to both the emotional and physical needs of children within the home [34]. Similar to Gilligan, in their book, *Caring Democracy: Markets, Equality, and Justice,* Joan Tronto discusses how care is relational and a type of labor [122]. Tronto brings

forth domestic care activities such as doing laundry on behalf of a partner, changing a baby's dirty diaper, or cleaning the home, as examples of responsibilities in domestic life that are often viewed as feminine roles and typically gendered. To expand on prior theoretical examinations, Gram-Hanssen introduces their own interpretation of the ethics of care framework in their work, *Beyond energy justice: Ethics of care as a new approach in the energy system*, characterizing care as a method of upholding sustainable, domestic, energy practices. The author introduces concepts such as *care receiving based on responsiveness* [40], describing that for care to take place, energy systems require evaluative properties related to how resource consumption lends to an impact on the environment, such as the carbon footprint of different diets [65]. Gram-Hanssen also brings forth other concepts such as *caring about, based on attentiveness*, describing how care activities require the use of energy resources such as heating a home, or cooking a meal for a family member, which has been outlined as an important care activity in other CSCW works [132]. Moreover, the care framework is also being expanded in the context of HCI work. In Petterson et al.'s systematic review, the authors emphasize the concept *care as repair*, which describes care as restoring or maintaining social relationships in the advent of infrastructural or systemic breakdown [87]. Thus, the care literature surfaces that care activities should be acknowledged as forms of labor and are often gendered and performed mostly by women. Furthermore, researchers seek to frame care ethics as a method to understand the connections between sustainable resource use in domestic settings, care activities, relational positions (i.e., care giver, care receiver), in addition to how such topics are entangled with interdependency and social responsibility, such as driving an elderly parent to a health appointment, which is beyond an individual act.

A consistent finding across research on shared technology systems in the home, including sustainability related domains, is the value of household roles in shaping how technologies are used [8, 20, 50, 64, 78, 110]. Roles guide who performs specific tasks, such as managing finances [64, 127], doing laundry [98] or putting children to bed [111]. These roles are rarely fixed, often shifting dynamically depending on availability, schedules, or unplanned circumstances, a phenomenon some researchers refer to as role-switching [20]. Such shifts can sometimes lead to breakdowns in communication or missed responsibilities, which highlights the importance of understanding household roles when designing sustainable mobility technologies. Prior work at the intersection of ethics of care and HCI highlights that some household members are excluded or burdened from a shared system [87]. Moreover, the care framework seeks to emphasize relational positions, such as care giver and care receiver, and how such social systems are entangled with empathy, compassion, interdependency and responsibility. Household rules and norms, shared goals, and motivations also influence how tasks are organized and how technologies are used [63, 78]. These socio-cultural standards often govern the contextual use of domestic technologies.

However, mobility poses unique challenges when viewed through the lens of household coordination. Unlike other collaborative domestic routines, such as meal preparation or cleaning, which occur entirely within the home, mobility planning often begins at home, but the activity itself unfolds external to the home throughout the day. Coordinating transportation is sometimes a physically distributed, asynchronous activity, affected not only by household social dynamics but also by external constraints such as traffic, access to public transit, or work schedules. This makes mobility a difficult coordination task and an important opportunity for thoughtful EFI mobility design. Thus, designing mobility-focused EFIs requires accounting for this blended space of coordination. Systems must be responsive to household roles, routines, and goals, yet account for decisions that are made where household members are physically separated from one another, and whose needs and priorities may evolve throughout the day in response to environmental, logistical, or economic constraints. Moreover, examining household practices and preferences

through the ethics of care framework enables us to understand how EFIs can magnify care work, social responsibility, and interdependencies within the home.

2.3 Eco-Feedback Interfaces and Sustainable HCI

Eco-feedback interfaces (EFIs) represent a central strand of Sustainable HCI research, where the goal is to surface information about energy, mobility, or resource use to help individuals and households reflect on the environmental impact of their decisions. The design space of these systems is broad, ranging from individual mobile applications to shared household displays [17, 58], yet the underlying logic often stems from rigid behavioral models that emphasize and rely on persuasion behavior psychology. EFIs can largely be characterized as PI systems, promoting reflection of areas of sustainability such as home energy management [41, 54, 58, 134], waste management [3, 33, 120], and understanding air quality [76, 131].

Visual data representations are vital in eco-feedback systems to promote awareness and personal reflection [29, 31]. Most EFIs explored in previous works have made use of varying visualizations such as graphs [58], abstract scores [120], or the use of goals and milestones [32]. Other systems have examined technologies like augmented reality [28] or dedicated wearable devices [121]. In a large-scale review of eco feedback systems, Sanguinetti et al. surface that timing, frequency, data granularity, and behavioral responses all influence user awareness and sensemaking of such systems [95].

In initial inquiries of eco-feedback technology, EFIs were a common design approach to supporting environmental sustainability [22, 30]. However, some within the SHCI community have expressed skepticism using individual focused technology to address systemic climate mitigation [10, 11, 45]. Prior works have identified that EFIs consisting of persuasive strategies can indicate habits that are problematic [22] or simply propagate socially normative or acceptable sustainable behaviors [108]. Moreover, the community increasingly recognizes the deeply socio-cultural [45], political [10], and economic contexts of sustainability, drawing on perspectives that emphasize environmental justice and ecological limits [60, 105, 109]. Thus, in response to the previously outlined shortcomings of individually-focused technologies to support sustainable practices, we position our study between socio-cultural and individual contexts of sustainable practices by focusing on households, moving beyond examination of how EFIs can promote individual decision-making or behavior change.

Household-focused studies in HCI have illustrated the view that sustainability is shaped through collective coordination and tensions in everyday life [51]. Yet relatively few EFI studies have grappled with how feedback systems might account for such dynamics. Baretto et al. and Horn et al. deployed EFIs in family settings, highlighting how they can promote deeper inquiry into sustainable habits [8, 50]. Lytle et al. further contribute a framework to explain how sustainable practices are facilitated within homes, emphasizing that an individual's practices and attitudes often shape and are shaped by those around them [66]. Although this work provides some recommendations for how to approach the design of sustainability in household settings, there is still a need to understand how EFIs can support sustainable practices specifically for mobility within broader household contexts.

Therefore, we position our work within the theoretical perspective of ethics of care to understand how to support sustainable practices by examining the distribution of labor within households. Ethics of care enables us to understand how sustainable practices are entangled with interdependency, social responsibility, and empathy, they do not help us grasp how to facilitate clear design guidance and transferability in everyday life to support sustainable behaviors in transport systems [42, 129]. Thus we point to other frameworks such as EFIs and PI systems which provide useful, established design patterns for tracking, but their focus on individual choices and decisions

often fail to address the complex social dynamics in households. This individualistic focus is a well documented limitation, with a growing body of work demonstrating the need to understand mobility as a socially embedded practice [42] and highlighting the limited success of interventions that target individuals in isolation [99]. We therefore bridge these perspectives by using an ethics of care lens to understand how sustainable mobility practices are entangled with fairness, care, and social obligation. We then demonstrate how the tools of PI, traditionally aimed at individuals, can be redesigned and re-appropriated to address the social complexities, tensions, and inequities that exist within homes. In this way, we show how EFIs can move beyond being basic tools for individual persuasion but rather scaffolds for shared reflection and sense making in regard to sustainable practices around the home.

3 Methods

3.1 Study Procedures

We ran nine focus group interviews, one with each household, where most or all household members were present (see table 1). As might be expected for an interview study, especially in homes, young children and older adults engaged in the interview at various points in the interview but were less participatory overall. Interview locations were determined by the household, intended to be convenient for most household members. In addition to interviews taking place in participants' homes (2/9), interviews also occurred in public spaces such as local parks (1/9) and coffee shops (6/9).

Each interview had two main phases. First, we asked household members general questions about their perspectives on sustainability, household practices, patterns, lifestyle related to transportation behaviors. Second, we presented participants with four paper low-fidelity mockups of typical design strategies for EFIs in order to ground our conversation around the impact of household dynamics on use of EFIs.

The four mockups, presented in a randomized order, followed common EFI strategies described in prior work: (1) Sustainable route planning systems, which highlight more sustainable forms of transit (i.e., trains over personal vehicles) and/or carbon emissions associated with particular trips [4, 27, 39]; (2) Passive mobility tracking systems, which classify different modes of transportation and provide some visual overview [13, 19, 29, 32, 52, 73, 83, 86]; (3) Shared displays for home sustainability data, which summarize household practices, typically energy usage, in a display physically positioned in the home [8, 58, 100, 114]; and (4) Chatbots for behavioral sensemaking, which offer a different interaction paradigm for understanding emissions logs [37, 48, 69, 113, 136, 138]. The mockups we presented (Figure 1) were heavily inspired by prior systems, and sought to cover the breadth of technology strategies employed in EFIs. Following an iterative design process, the mockups were intentionally kept general to highlight different interaction and data presentation strategies, rather than representing specific household configurations or data over fixed time periods. The lead researcher introduced each mockup to the household, asking questions regarding participants' initial impressions, potential benefits, and drawbacks to the design strategy in their specific household context. We also asked general questions about participants' typical routines and broader mobility patterns within the home (e.g., grocery trips, school drop offs).

At the end of the interview, we sent each household a gift card including the total compensation for each participant. We compensated adults (18+) with a $25 gift card, teens (13-17) with a $20 gift card, and any children (6-12) with a $10 gift card. We did not compensate household members who were not present for the interview, and young children (ages 0-5) who did not participate. However, participants occasionally alluded to their presence, so we list them as part of our summary in Table

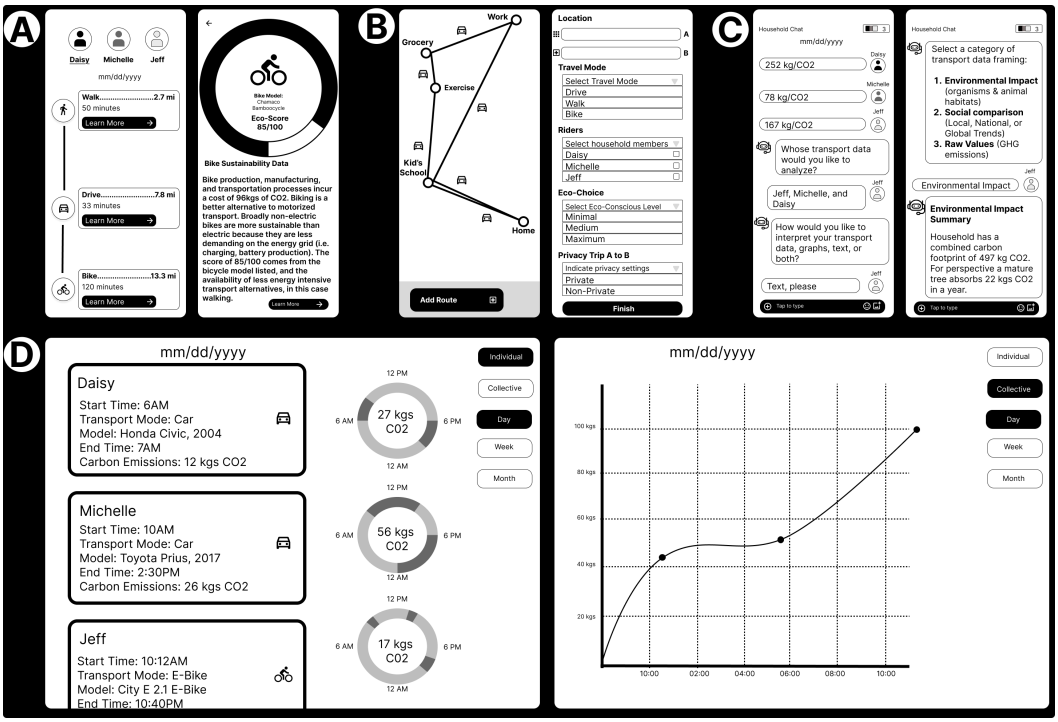


Fig. 1. Mockups of Sustainable Mobility Designs Shown to Participants. **A**. An application that classifies modes and transit and gives short overviews of how it relates to sustainability and the environment. **B**. A route planning application that helps users map out their trips in an environmentally friendly and convenient manner **C**. A chatbot based messaging application that guides users collectively towards making sense of their carbon footprint data from mobility decision **D**. A shared household display used to help households reflect on their mobility choices and see trends collectively over time.

1. Interviews lasted on average 70 minutes (Min=47:17, Max=93:12). The interviews were conducted in accordance with our university's IRB protocol.

Focus groups were recorded and audio was transcribed, first automatically using an android-based recording app and manually corrected by the first author. We used inductive thematic analysis to analyze the interview transcripts, generating open codes and regularly comparing them to surface underlying themes [9]. The first author open-coded the interview transcripts, pulling out representative quotes from participants aligning with four major themes. Early themes included multi-member transit planning in everyday life, use of apps for monitoring sustainable practices, and concerns around the labor of household mobility monitoring in everyday life. After discussing the themes with the rest of the research team across multiple debriefing meetings, we settled on a main interest of how the social relationships and coordination between household members influenced their perceptions of EFIs. We then re-analyzed our transcripts and interview quotes around two main themes: the impact of household structures and the influence of household communication patterns, with six sub-themes. We used these to organize our findings. We then used the ethics of care framework [34, 122] to interpret our findings, shaping our recommendations for how we could approach designing EFIs to align with household needs.

Table 1. Participants with * are considered part of the household but either 1) could not be present for the interview or 2) were below our protocol's age limit.

Participant (Gender, Age)	Highest Education	Household Income	Household Type	Location
P1 (W, 49), (W, 15)	Bachelor's Degree	$40,000 - $59,999	Family	Suburban
P2 (W, 60), (M, 65)	Master's Degree	$120,000 - $139,999	Family	Urban
P3 (W, 56), (M, 58)	Some College	$140,000 - $159,999	Non-Family	Suburban
P4 (W, 54), (W, 15), (M, 52)	Master's Degree	$140,000 - $159,999	Family	Suburban
P5 (W, 69), (M, 67)	Bachelor's Degree	$100,000 - $119,999	Non-Family	Urban
P6 (W, 81), (M, 56), (W, 54), (W, 21)	Doctorate or Professional Degree	$140,000 - $159,999	Family	Suburban
P7 (*W, 4), (W, 6), (W, 33), (*M, 37)	Master's Degree	Above $200,000	Family	Suburban
P8 (W, 22), (M, 21), (*M, 1)	Associate's Degree	Less Than $19,999	Family	Urban
P9 (M, 29), (W, 27)	Master's Degree	$100,000 - $119,999	Non-Family	Suburban

3.2 Participants

We recruited 21 participants across nine households through various platforms such as Craigslist, LinkedIn, and Discord. On these platforms, we shared a flyer which detailed eligibility criteria and invited participants to fill out an introductory survey on behalf of their household. We required households to 1) consist of two or more people, one of whom was at least 18 or older who were willing and able to participate in the study, 2) to be located in the broader area of our university and 3) have regular conversations regarding household tasks, routines, and/or plans in the home. We restricted participation to multi-member households, and households where multiple people were able to participate because we sought to understand how household dynamics impact perceptions on opportunities for technology to support sustainable mobility. Moreover, we restricted participation to our local community in order to support in-person, richer discussion. We further imagined that it may be challenging for multiple participants in a household to engage with a video call, and in-person enabled us to better engage all family members. Given that some households may not actively communicate with one another about household tasks (e.g., roommates who largely live independently), the final eligibility criteria ensured that some interpersonal dynamics would be present. Participants also provided other information in the introductory survey, such as demographics, as well as an adapted and shortened version of the environmental concern questionnaire used in prior work [74]. We used this questionnaire to understand participants' attitudes toward sustainable practices coming into the study, but not for evaluating eligibility.

Our participants had higher incomes compared to the national average, where many (7/9) of the households reported annual household income ranges above $100,000. Our sample also indicates that many households (7/9) were highly educated, with seven households having at least one participant with a bachelor's degree and five having a member with a postgraduate education. Most of the households reported living in a suburban context (6/9). Households were a mix of family households (6/9), where all family members were related, and non-family households (3/9), consisting of domestic partnerships (2/3) and roommate living arrangements (1/3). The average age for participants was 43 years old (SD=21.1) with both women (14) and men (7) participating. On Miller et al.'s environmental concern questionnaire [74], participants were broadly environmentally conscious, with a median score of 22 out of 25 for environmental concern, and 23 out of 25 for environmental values. The full summary of the participants can be seen in table 1.

All participants were located in a large metropolitan area on the West Coast of the United States. All of the (9/9) households had access to a personal vehicle. When asked how often people in the household use different modes of transportation, many of the households (7/9) reported 'always' or 'often' using a personal vehicle. In addition, many households (7/9) reported 'rarely' or 'never' using public transportation. Furthermore, only some (3/9) households mentioned walking 'often'. Moreover, many (6/9) households reported using a bike/scooter 'rarely' or 'never'. To further

contextualize these responses, the walkability scores for households' zip codes (when available) which varied from 47-75 out of 100, with lower transit scores (32-33 out of 100) but higher bike scores (71-74 out of 100), with scores below 70 indicating moderate to poor support for the mode of transit [1]. These responses suggest that the households' use of different modes of transit was largely shaped by the availability of infrastructure alongside their personal preferences, which overall leaned towards a car-centric environment.

3.3 Limitations

Though our study arrived at fruitful findings, various limitations should be acknowledged. Primarily, though we aimed to recruit people with various perspectives regarding the environment because the nature of our study was advertised through the lens of sustainable household mobility, this may have attracted people who had greater concerns, interest, or experience with the topic. Future work might potentially include how households with no interest or concern for the environment might engage with sustainable mobility data. Although we felt we reached thematic saturation, we note that our small sample size was unable to fully account for the diversity of households and household structures within our geographic region. Namely, the household incomes of our pool of participants were notably higher than the national average. Thus, more work in the future should seek to include participants from a more varied socio-economic background. In addition to recruitment criteria, despite us deploying focus group interviews in households, because these individuals were familiar with each other, which is not typical for focus groups, the interview settings possibly did not fully encapsulate what a typical focus group looks like, making people less forthcoming, which may have made it difficult to garner any conflicts or tensions that may exist within the home. Lastly, the types of households we interviewed were not exhaustive of all household dynamics. Future work should aim to understand how homes comprised of different social dynamics (such as divorced parents, foster homes, etc.) navigate the sense making of sustainable mobility decisions jointly.

4 Results

In this section, we present findings from our qualitative analysis of focus group interviews. We found that sustainable transit decisions were often shaped by the need to accommodate other household members, and that household roles influenced how individuals perceived eco-feedback tools. Moreover we found that differences in environmental concern sometimes created tensions within the home. We also observed that eco-feedback interfaces often acted as scaffolding for conversations about resource consumption, providing a starting point for reflection and negotiation among household members. Lastly, we find that household members had varying preferences for data visualizations. In the following subsections, we illustrate these dynamics in greater detail with examples from participants.

4.1 Impact of Household Structures

Participants emphasized how household structure often influenced their mobility choices, and therefore the utility of EFIs towards supporting sustainable mobility. Structural influences included the needs of others, varied and imbalanced household responsibilities, and differences in level of environmental concern.

4.1.1 Planning Around the Needs of Others. Interview participants often emphasized how planning around the needs of other household members often influenced or interfered with their ability to make their desired sustainable transit decisions. This was often notable in family households, where needing to coordinate rides for children made it challenging to adopt sustainable modes of transit. For example, P4M, 52 expressed how his and P4W, 54 routines revolved around the daughter's

(P4W, 15) school and extracurriculars, which influences his ability to commute by bike: *"The big part is [...] okay, where does she need to be at what time, and which one of us can be around to pick her up or drop her off or both. I mean, I would like to bike, and some people do bike, but I don't really want to get to work sweaty."* The daughter chimed in to add, *"and he has to drop me off anyways"* (P4W, 15). P4M, 52 continued, *"Exactly, so those are the trade-offs that we go through every single day. So, that's why we typically stick with a car."* In dual-parent households some parents described this as a, *"tag team... [which can be] very chaotic"* to deal with (P7W). While some participants like P7W, 33 stated that they would like to maximize their sustainability practices, it proved challenging given the needs of other household members, *"I mean, I would love to walk to your [daughter's] gym, but it might take us several hours."* Though households often aimed to use sustainable methods of transport, they also mentioned valuing flexibility in where they go and how they get there. P4W, 15 highlighted how planning to take a car can enable adapting their transit plan to allow for another destination: *"they [parents] pick me from school. And we were originally going to go straight to math class, but we're like, oh, we have time to go to [a restaurant]. Let's go to [the restaurant]."*.

For many households, the amount of coordination and planning needed for transit in day-to-day life did not leave space for considering sustainable transit. P5W, 69 highlighted that her disability, together with financial needs led sustainability to be a low priority, saying *"my personal issues of transportation have become very complicated with my back pain, because if I want to go somewhere, I have to ask him [P5M] to put the walker out in the car the night before or in the morning... I just feel like when you're in a situation where basic needs are barely being met, it's not like I can be spending all this time worrying about sustainability. I just can't do it. It's like most of my time and energy is either looking for work [or] doing the work."* Similar sentiments were expressed by other households with complex life factors. For example, P8W, 22 highlighted complexities arising after the birth of her child, leading her to make less sustainable decisions: *"We have more responsibilities we need to do and more things we need to do together than before [son was born...] I had to DoorDash milk, because we had no milk, it went bad. It has its days. Some days are like easier than others. Some days I could say it can be a little bit overwhelming with everything."* From the interviews, we find that the challenges in making sustainable decisions often stemmed from household members needing to prioritize and consider the daily mobility needs of other members in the home. As a result, considering more sustainable mobility practices was viewed as an added burden and largely avoided because it required additional consideration alongside the challenge of supporting the mobility needs of people within the home.

4.1.2 Coordinating Alongside Other Caregivers and Support Network. Throughout the interviews, participants mentioned the inclusion of people who were not part of the home who assisted with mobility related activities which would have carbon impacts that may be challenging for EFIs to recognize. For example, P7W, 33 hired external help to facilitate household tasks which could not be met by the parents. They, *"have a nanny that will help with all of the pickups for school, like morning drop offs and after school care when I'm working."*. Participants frequently brought up use of rideshares, as part of assisting with mobility challenges. For example, P8W, 22 mentioned that *"if he [P8M, 1] hurts himself I have to figure out an Uber or something else because we have no family out here. I'm gonna have to figure something out if I have to take him to the hospital or something."*

Other participants mentioned reaching out to neighbors or family friends for the support of mobility related activities under special or atypical circumstances. For instance, P1W, 49 mentioned that they sometimes relied on their neighbors for carpooling, *"because when my car was getting repairs, that's essentially, what I ended up doing with my neighbors. I'd reach out to my neighbors saying hey, if you're going somewhere, will you let me know?"* Similarly, P4M, 52 mentioned that when considering how to support their daughter in mobility related options they, *"sometimes*

consider, even though she [P4W, 15] doesn't like it, getting picked up by family friends or friends' parents." Because of this reliance on external household members, some participants highlighted the attractiveness of viewing sustainable mobility data in a communal context. For instance, P1W, 49 mentioned that it would be useful if they could see *"anybody in my area that is part of my circle [through an EFI], and where they're going today. For example, Oh, we're going over here today. Like a collaborative community sort of carnival."*

4.1.3 Care Responsibilities Around the Home. Mobility roles within households are rarely equal. Work, school, or caregiving responsibilities often lead to imbalances in who bears the transportation burden. For example, P8M, 21 mentions they, *"just transferred to [university 20 miles away], which is a [necessary] drive for school and for work."*. Similarly, P3W, 56 is equipped with the caretaking responsibilities for their older adult parents by, *"go[ing] to my dad and I pick him up to go see my mom, [because] she's in a nursing home."* When considering how carbon expenditures could be presented, interview participants emphasized that these imbalances in tasks, roles or needs related to household functioning might exaggerate one household member's carbon footprint. For example, P6M, 56 highlighted that his wife who may have a higher carbon footprint because of the household tasks she typically takes care of: *"So, my carbon footprint for the day may be fairly low, because if I just drive to [place of work], then I work, spend 12 hours there, and then go home and jog or something. Whereas she might have to visit her parents, or take them to the ER Urgent Care, then pick up prescriptions, then go to the market, or she may have to pick up [daughter] from the airport. So she's doing all those things. But it's not that she's less carbon efficient than me. It is just that what [her] duties are for that day."* P7W, 33 suggested that a similar trend might surface in her household based on her responsibilities: *"I do a lot more of the driving the kids around type things, so I would probably by nature just have more output carbon emissions [than P7M] just because he often is [only] driving to and from work. Whereas I'm doing a lot of the errands and appointments and stuff... just by nature, I think a lot of families [...] will have one person doing more of the tasks than the other."* P7W, 33 further noted that her household responsibilities differed between weekends versus weekdays, but this might not get accounted for in EFIs *"My husband does a lot with the kids like on the weekends and stuff when I'm working especially. Like, so I'd see that [in an EFI], but [...] that's two out of seven days versus like the five. I wonder if you could do it based off of overall [emissions]? To make it fair, like actual miles [driven]. Because then [...] even though he does less time, but [considering] in the time that he's doing it. Like, miles per day, or something like that."*

4.1.4 Disparities in Environmental Concern. Household members varied in how much they emphasized sustainability. P6M, 56 highlighted how different family members would set different transit goals: *"Her [P6W] [environmental] goals are a little bit more [ambitious] than mine."* P7W, 33 similarly highlighted, *"I'm more passionate about the environmental stuff. Whereas my husband sees more of the financial waste that happens, not so much the eco waste."* Non-family households similarly pointed out differences in perspective. For example, P5W stated how her housemate has a greater interest in sustainability than herself, saying *"He [P5M] has this real big interest in electric bikes, and he's been wanting one for years, and when he worked in [city], he was talking about getting an electric bike and commuting all the way to [city 30 miles away], which I said was nuts."*.

These differences in perspective around sustainability and sustainable transport sometimes led to tensions, conflict, or frustration when transit decisions needed to be made. For example, P2W, 60 discusses her daughter, *"who lives at home, is a typical American. She goes all over [the area]. Last week she told me [she] is going 14 miles to visit a gym. I don't like driving, but for my kids they'll go all over. If I talk [to my kids] about it [sustainable driving] they don't want to hear it."* We see this in other households where some members feel as though their collective practices could be improved related to transportation and mobility. For example in an interview P6W, 21 mentions

"I think we do overuse our Amazon Prime [though]. We order way too much on Amazon. Because they have to bring it to us from the warehouse." P6M then replies *"well, I will argue that [it's not as bad because] we don't have to go to the store."*. Moreover, participants suggested that misalignment could lead to differences in the utility of EFIs. P4W, 54 puts it bluntly, *"I'm not sure how terribly useful [a household EFI would be] because what comes to my mind is [that] I don't care about CO2."* Following this statement, the daughter attempted to scold her mother in Mandarin, highlighting the differences in perspective. Through the interviews, we find EFIs for mobility surface tensions for people on both sides of the environmental concern spectrum. Moreover, the EFI designs were sometimes perceived to surface distinctions between individual sustainability priorities within households, which could present some perspectives as more valid than others.

4.2 Communication Patterns around EFI Designs

Building on their household dynamic, participant perspectives varied around how EFI designs would align with their pre-existing communication patterns or support their practices. We describe participants' view that EFIs could help scaffold conversations around sustainable decision-making, and contrasts among household members based on their roles and identities.

4.2.1 EFIs as Collective Conversation Scaffolding. Households differed not only in whether they valued sustainable mobility data, but also in how they wanted to engage with it. Some households saw EFIs as scaffolding for household discussions, similar to how they already talk about errands, costs, and planning. For instance P5W, 69 mentions that, *"if we do errands together, which we sometimes do, we try to put them all together because of the time constraint. It just takes so much time to get around everywhere ... So, I think anything that can help save time and get stuff done. I really like that travel planning one and then, you could incorporate the carbon footprint [EFI/mockup] into that and show that as one of the things you're saving by doing this, this, and this together."* Other participants agree that tracking this data would be useful to organize their daily life tasks in addition to helping them save on gas as a result. For example, P8M, 21 mentions that, *"This [travel planning app] would be really good for planning a day out, if we wanted to go, pick up some snacks at the store, head to the park, eat lunch, hang out. And even with the cost effectiveness, since gas is pretty expensive. So, maybe finding the the best way to save on gas, but still make it to our destination in a reasonable amount of time [might be most useful for us]."* Towards these discussions, some households felt that sustainable mobility data could be a useful frame of reference to ground conversations and keep household members accountable. Take for example a quote from P3M, 58 where they say, *"everyone could be accountable if you see what they're doing as opposed to [just] what you're doing. Yeah, and then it could lead to discussions about... hey, [person]'s, like, oh, you know what, I'll go [run an errand], get there two hours earlier and get there without the traffic....Saving money on gas wear and tear on the car and [lower] CO2 emissions."* These perspectives surface that household members valued that the EFIs could help ground their communication practices in collective data, which could facilitate greater discussion around saving time, money, or energy. Participants anticipated that these conversations would help their households establish or adapt to more sustainable transit decisions.

In households which had less collaborative discussions around resource management, members felt that EFIs would feel irrelevant, either because there is little perceived collective interest in resource management tracking or these conversations are not pervasive. Take for example this set of quotes from the P4 household, where one member (P4M, 52) was most interested in engaging with an EFI for mobility data, *"we're used to seeing something like this [household tablet mockup] already, because we got [mobile app with integrated electricity tracking hardware] to trace our electricity usage"* (P4M). P4W, 15 joined in and asked, *"You look at that?"* to which P4M replied *"Yes, I look at that. So,*

something that I still try to figure out is, Which one [household EV vs gas car] is really the most cost effective? Right, because we pay quite a bit for our electricity these days." Shortly after this, when P4W, 54 was asked what their thoughts were on the design, they mentioned that the EFI may not be very useful for them because they, *"just need to know the car has gas."*

4.2.2 Contrasting Representation Needs Between Household Members. From the interviews, we found that household members often had different preferences around how EFIs present their data, whether they be on a shared device or through individual applications, which made it unlikely that a mockup would support the needs of all people in the home. Some participants expressed hesitancy or disinterest in engaging with their sustainable mobility data individually through novel mobile apps or systems. Take for example this excerpt from P4W, 54 who exclaimed that, *"There's too many apps! Just another app would not be useful unless [there] is a [strong] need. Otherwise, I don't think I'll install this to get the data."* However, shifting the medium to a shared device, such as a household tablet, introduces its own set of challenges, primarily that a single interface often fails to meet the divergent representational needs of all household members. For example, in an interview with P7W, 33 they mention that, *"My husband would like this [household tablet mockup] Yeah, he's a data spreadsheet graph, guy... I think to grab their [kids'] attention, [they would like this agent-based mockup because...] especially my older one [kid] is into living organisms and animal habitats. So to be able to look at how this is impacting what animals we live around, not just humans. She would love that type of stuff, and then I could show her, and it would be like she had this comparison."* Others similarly pointed out how representation preference might differ between household members. For example, in the same household P6W, 56 mentions that, *"For myself, I start to gloss over the numbers [in the household tablet mockup]. It doesn't have meaning anymore to me, because, I don't lock into numbers naturally, like some people do like my son might, and he might really pay attention to that... I'm, like, I don't understand this. But if it was like bar graph yeah, that would be better."*

Households often expressed different EFI presentation preferences depending on their personal sustainability goals. For example, P9M, 29 mentioned that, *"The eco score would be good for me because then I could learn more about this topic... Yes, even if it is abstract. Because then I can know more about sustainability"* whereas P9W, 27 thought that the *"Chatbot [mockup] would be more interesting if I could get more information about my carbon emissions. It would work if it is helping me understand [the impact] of my travel habits."* This suggests that P9M was most interested in using EFIs for learning about the topic, whereas P9W sought to more deeply understand their habits.

These varying visualization needs stemmed from participants' daily transit practices. Household members who drove often indicated the importance of presentation strategies which could record and map out their routes. For example, P7W, 33 described relying on maps for daily errands but desiring greater sustainability information, *"I still have to use Google Maps to drive places because I don't pay attention.... but, if it [route planner mockup] could replace [google maps] by giving this [sustainability data], I would have no problem jumping ship."* For household members who were not as responsible for driving, they failed to see the value in sustainable route planning. For example, P4W, 15 describes: *"I feel like this [route planner] mockup could be confusing. For example someone that walks out of their house, then to the bus stop, and then they take the bus to work, and then they rent a bike and go to the restaurant, and then they drop the bike off at the restaurant, and then they hop on a taxi to go home. It's hard to do think about this, you know?"*

In contrast, household members who had a broader ecology of transport behaviors found summarization features more suitable for their needs because they helped make the tradeoffs of transit modes more apparent. For instance P8M, 21 mentioned that, *"the chatbot [would be interesting because it] could say instead of spending, or emitting 12-13 kilograms of CO2 [over] a mile drive, maybe you could walk or bike for an extra 20-30 minutes. That way, you're still trip planning, but*

you're trying to be [actively] more conscious about what the [different] carbon emissions that you're creating." For some household members, the text-based features of the chatbot design was most useful in conveying these tradeoffs. However, for some, the transport classification tool appeared to convey information in the most supportive way. For example, after examining the mockup, P3M, 58 mentioned that the design was helpful because it facilitated his comparisons visually between the different transport options available to him, *"I walked 2.7 miles, right, burned a lot of calories, walking 50 minutes. Maybe I would get a new driving route because it took 33 minutes to go seven miles. But yeah, that would be interesting. I gotta figure out a new route, or maybe go earlier when there's not as much traffic. I can see that being helpful as far as maybe changing up the routes so I won't be sitting in traffic...Cause that drive is like a [densely populated city] drive. I mean we only went 7 miles in 33 minutes. An electric bike ride, that would be much quicker, less gas, burning CO2. It would be good for also changing that travel mode."*

5 Discussion

Towards our research question, *How can the design of EFIs account for the dynamics and social structures in households to better promote sustainable mobility practices?*, our interviews resulted in four primary findings. First, the design of EFIs helped surface that households had different reasons and motivations for communicating around resource use within a home. Second, we found that planning sustainable mobility in households requires navigating the challenges of day-to-day household life, where fulfilling basic needs may interfere with individuals or households from reflecting on their transit practices. Third, we find that the design of EFIs illustrated the variance in value systems regarding sustainability within households often leading to friction in the home, influencing how they perceive the utility of technology towards supporting sustainable practices. Lastly, through the design of EFIs we find that the mobility imbalances that occur within households are often unequal and need to be accounted for in the design of sustainable mobility tracking tools for households.

We discuss how EFIs and other systems designed to support sustainable practices could better account for household dynamics and household inequities in carbon footprints. We further elaborate on how these systems could support collaborative discussion and balancing group and individual needs.

5.1 Collaborative Negotiation of Sustainable Mobility Data

Prior studies have included EFIs in household settings, emphasizing that accessibility of EFIs in homes can support inquiry and contextual-based learning [8, 50]. We extend this line of work by demonstrating that though the households may be closely aligned in their sustainability ideologies, the extent to which they practice these beliefs can vary from person to person within the household, which can lead to frictions in the home. This observation aligns with past literature suggesting that environmental attitudes are not strong indicators of pro-environmental behaviors on an individual level [61]. Though past works have demonstrated that the presence of other people in the home can both help or hinder sustainable practices [51, 66], using an ethics of care lens in this work, we highlight that frictions arise not just from different individual values or behaviors, but from misalignments in awareness of care responsibilities in the homes. Because of this the shared meanings (e.g., what counts as a 'necessary' trip) that constitute the practice of household sustainable mobility negotiation, becomes obscured within the home. According to prior work using care frameworks, taking care of a fellow family or household member is sometimes necessary when viewed through the social standard of what is considered of being a good flatmate or parent [18, 38]. While parents can make their children take the bus, for example, as a more sustainable

option, this does not align with many people's perception of what is considered to be a caring guardian.

If EFI data are taken literally, people in the home with responsibility for care might feel compelled to make those with less power (e.g., an elder parent, child, flatmate with a disability) to make more sustainable choices. Yet in practice, our findings suggest that people prioritize their care responsibilities over promoting sustainable choices, which is in-line with prior work using the ethics of care framework [18, 38]. Moreover, as others have described, suggesting sustainable resource consumption through tracking technology could be communicated as denying care [68] by using these tools to rationalize subjecting people to worse qualities of care which leads to friction and more interpersonal conflict. Though our findings may not demonstrate that households will fundamentally use EFIs to start carrying out care activities on behalf of others in more environmentally sustainable ways, they do show that these people are open to using tracking interfaces to collectively assemble and negotiate the efficient allocation of time and resources jointly as opposed to individualistic models posited in prior work [42, 99]. Moreover, through our findings we see that in the American context, this information can help households manage resources like time, money, or energy while navigating daily life tasks (e.g., going to work, dropping kids off at school, going to the grocery store) in a sprawling, suburban, U.S. landscape where alternative forms of transport do not always lend to more sustainable outcomes [62]. This contrasts with prior studies in different sociocultural contexts, where the purpose of sustainable mobility data may instead be to support alternative forms of transportation [44], which is less realistic for our participants.

Our findings also demonstrate that many of the households we interviewed relied on external support networks in getting sustainable mobility needs met, which confirms and extends existing literature on the critique of EFIs which have drawn attention to the limitations of examining the behaviors of individuals in carrying out sustainable practices alone [10, 11, 45]. Moreover, we saw this where mobility related care needs were sometimes in excess of what the care givers could provide, whether it be connected to resources or time constraints for work. Using the care lens this dynamic can be described as *care as repair*, a concept introduced by Petterson et al. [87]. In their systematic review the authors highlight how care emphasizes the restoration or maintenance of social relationships in the advent of infrastructural or systemic breakdown. While their argument characterizes care relationships in natural disasters, we see this happen on a smaller scale related to mobility in daily life. People may not necessarily seek external household reliance, yet our data demonstrates they do so either when challenging life events occur (e.g., a car breaking down) or when household members are not able to meet the care needs of others within the home. When considering tracking in EFIs, household related mobility activities may be difficult to account for because households rely on other support networks to get their care needs met which traditional eco-feedback interfaces, in areas such as waste management [3, 120] and home energy usage [41, 58], fail to account for.

Furthermore, our results suggest that sustainable mobility data engagement seemed to be most promising where households already have regular collaborative discussions about resource usage management. Though some researchers have suggested that EFIs help facilitate discussions regarding sustainability and resource management [58] or increase accountability [8], our work indicates these practices exist in many households, relating to Gram-Hanssen's concept of *caring about, based on attentiveness* [40] where household members were well aware of resources needed to carry out care activities, such as needing gas to get groceries, or electricity to fuel an EV to drive another household member to school. As a result of this, participants found that EFIs help ground conversations by surfacing information about their sustainable practices, what care responsibilities exist within the home, in addition to helping them better manage their energy resources.

We see opportunities for more formal studies to understand how environmental behaviors are carried out within the home, who are the people that typically push for these activities, and what methods technology can support these processes and negotiations within the home.

5.1.1 Design Recommendation. To support households in moving from household interest in sustainability to guiding household discussions, we highlight the benefit of conversational features as demonstrated in other research contexts [136]. Recent work has also begun to explore the use of conversational agents to scaffold reflection on environmental behaviors in the home [35, 36]. Future EFIs could draw on these approaches by presenting open-ended prompts or cards such as, *"How well are we managing our carbon footprint this month?"*, *"Can we use public transportation for any upcoming group trips?"*, or *"How can we limit the carbon footprint of after-school activities?"*. Because transit decisions are undertaken outside the home, collaborative discussion cards, or broadly conversations can serve as a useful recentering point for households to recap, summarize, and reflect on collective sustainable transit habits as suggested by prior CSCW work in family coordination technology [132]. Providing such a feature, even if it lends to some conflict regarding differing views towards sustainable mobility, potentially offers households an opportunity in building strong socio-emotional bonds with one another, in addition to a healthy sense of group/familial identity [79, 98, 132]. Conversational features can also support households in discussing how care activities evolve as people age, have new needs [87], or as inter/intra household social relationships change [23, 137]. For example an EFI can display questions such as, *"Does anyone envision having new mobility needs this year?"* Moreover, these prompts need not necessarily be prescriptive, but can instead serve as conversational triggers that support households in collectively interpreting and acting on sustainability data as opposed to indicating problematic behaviors, a drawback outlined by prior critiques of EFIs [22, 109].

While large language model (LLM) based agents are one possible implementation, the core value lies not in the use of the agent itself, but rather in the contextual prompts EFIs provide as a space for collaborative dialog. Despite AI agents serve promising in facilitating dialog, if incorporated into EFIs, it is important that researchers examine if the energy and environmental costs associated with these systems outweigh the benefits. Given the increasing environmental impact of AI [55] using these systems within EFIs necessitates active reflection by researchers and designers seeking to deploy and develop these tools for more sustainable outcomes. However, we see particular value in using prompts to scaffold the household's own reflective conversations, grounding their existing care practices in data which might facilitate joint definitions around what are environmentally considerate actions within the home.

From an ethics of care lens, these sorts of conversations could potentially open up a dialog in households about what specific care activities are necessary or excessive, such as why transit to specific locations (e.g., a child's friend's home, a specific gym) are important to the well-being of individuals within the home [40]. This can help shift attention from each person's carbon footprint to the task.

5.2 Carbon Footprint Inequities in Household Tracking

Our findings reveal a critical conflict between the individualistic accounting of traditional EFIs and the lived reality of care work in households. For example, many participants expressed concerns about the imbalance of tasks that regularly occur in households, and how this can exacerbate the carbon footprint of one or more household members. Though the existence of inequitable roles in households has been widely discussed [8, 20, 64, 98, 110, 127], our study surfaces people are not only aware of these roles, but expressed concern about how these responsibilities might shape their contributions to the household's data unfavorably. This finding is in-line with other CSCW works

highlighting how labor in homes are not only inequitable, but also go unacknowledged by people in the home [79, 98, 137]. In the households we looked at, we see significant forms of care work that might impact who has the greatest (measured) carbon footprint such as driving a child to school or taking elderly parents outside of their home to visit others. Such findings are well aligned with prior critiques of EFIs which emphasize that individual examinations often fail to outline justice and fairness oriented perspectives in the context of sustainable practices [105, 108, 109]. Moreover, such activities are important for household functioning and well being yet this labor potentially penalizes household members, through carbon footprint data, for taking care of one another in traditional EFIs [32, 75, 86]. This logic reveals that the underlying premise of many EFIs, quantified outputs for related mobility actions, is incompatible with the relational/social nature of households in addition to what responsibilities each member of the home carries out.

5.2.1 Design Recommendation. Following an ethics of care framework [34], one potentially promising strategy to contextualize emission inequities is data annotation, where household trips associated with care activities as depicted in figure 2. For example, in a family setting, emissions associated with driving for a school drop-off could be attributed to multiple passengers, or labeled as non-discretionary as depicted in figure 2B. A trip where multiple household members may benefit from, like grocery shopping on behalf of the household, could similarly be annotated as depicted in figure 2C. These sorts of annotations and attributions have been suggested in other personal tracking contexts, particularly in health and well being, to help improve communication and understanding in multi-stakeholder settings [6, 56, 90]. This approach has the additional benefit of supporting household members in individually reflecting on their emissions relative to the household, which could support comparison and further discussion. Moreover, data annotations could help make care work visible and allow its carbon impact to be socially negotiated and re-attributed, aligning the data with the household's shared reality.

A challenge to contextualizing emissions is that adding additional labor to annotate can make the process more burdensome, and therefore less feasible especially in light of varied commitment to sustainability behaviors [7]. Moreover, this annotation labor may in itself become another inequitably distributed task, placing extra burden on the household members already performing the majority of the care work. To mitigate this, we suggest that systems could partially automate annotations by, for example, categorizing trips based on frequented destinations (e.g., school, grocery store), or even allow a user's trips to be categorized as collective by default, and prompting for confirmation rather than requiring manual entry from scratch. Nonetheless, it is important to recognize that even contextualizing data may add to the overall labor of an individual within the home.

5.3 Creating Space for Reflection of Sustainable Mobility Data

Common approaches to designing EFIs frame sustainability through a personal behavior model [31, 75, 93, 95, 120]. Our work highlights that this approach may be less effective, when considering sustainability practices in households. Each individual is part of an ecosystem of social, caring relationships and interdependencies, which informs how sustainable decisions are both made and distributed. Moreover, our findings confirm and extend prior work to highlight that families and households are not monoliths, with varied motivations, interests, and challenges around collaboration [106, 114], while further extending the well documented critiques of EFI which emphasize the limitations of an individual's ability to impact larger sustainable goals [11, 22, 45].

Viewed through the lens of ethics of care [122] household sustainable mobility can be characterized as an assortment of tasks delegated to a few or a single person in the home. Moreover, from our study we found that because care is exhibited primarily by certain individuals, these individuals

in the home often, whether explicitly or implicitly, soak up the mobility related responsibilities of one or many individuals within the home. For example, parents responsible for taking a child to school may not often share the energy needed/required to engage in care activities (e.g., how much gas or electricity needed per mile). As a result of this, care givers insulate the receivers of care, where the receiver becomes separated from the energy system, lacking the aptitude/competences needed to understand the resources whether they be tangible or intangible. For example, teens who get driven by parents may not understand how much gas/electricity is used for a week's worth of care activities. Similarly, they may not be as informed as care givers as to how, when, and where certain care activities are carried out. Thus, because of this lack of communication, intentional or not, the process of evaluating the impact of using resources whether they be environmental (gas, electricity) or intangible (cognitive burden of planning) as others have highlighted [87], is lost upon care receivers. This concept is otherwise known as *care receiving, based on responsiveness* introduced by Gram-Hanssen[40]. Gram-Hanssen argues that care receiving, based on responsiveness demonstrates that energy systems require evaluative properties related to how resource consumption lends to an impact on the environment, such as the carbon footprint of different diets [65] or household heating behaviors [38, 68]. However, it can be difficult for certain people in the home to reflect on the environmental impact of care activities if they are facilitated on their behalf and with no frame of reference for how energy intensive these practices are. The argument here is not necessarily to use EFIs to confront household members with how much carbon emissions or gallons of gas certain activities require. Our findings suggest this might have the opposite of the desired effect and deter household members from becoming involved in sustainable mobility. Rather, here we are saying that the communication and collaborative dynamics of how care activities are produced, are simply not conducive to developing an understanding of how to engage with sustainable mobility data, for those who are the beneficiaries of care (e.g., children, older adults).

As a result of this insulation, receivers of care may not understand metrics associated with mobility activities. Moreover, this explains why the EFIs presented to participants, consisted of data visualizations that were tailored towards the representational needs of one or a few people within the home, which is characteristic of prior work in shared household information management systems [79, 98, 117, 127]. This also explains why the concept of sustainable resource consumption or energy limitations was particularly foreign for some people within the home. Thus, because of this unfamiliarity, important considerations in tracking contexts like data literacy [112], self-reflection of data, and forming a personal environmental identity [77] may seemingly be difficult for a person who is the receiver of mobility related care. Therefore, our findings suggest that a single household interface, whether individual or shared, struggles because it cannot simultaneously support the different competences required to reflect around sustainable mobility data for both care givers and care receivers.

5.3.1 Design Recommendation. We see opportunity for household EFIs to leverage care activity budgets, credits, or limits as depicted in figure 2A. For example, an EFI could display care activities with associated energy emissions that could be tallied into a monthly energy or emissions budget (e.g. kwh or CO_2). Recent work has suggested incorporating carbon handprints (e.g., positive climate impacts) over footprints (negative impacts) might be a more beneficial approach for supporting engagement with sustainable data, particularly for early sustainable actors, possibly supporting them in developing an environmental identity [124]. However, prior research has indicated that for adults, negatively framed carbon footprint data (e.g. 25 kg CO_2 emitted for this trip) is a stronger indicator for making more sustainable transit choices [75]. As a result of this we see carbon handprints being useful for younger audiences or individuals who are new to learning about the environmental consequences of their actions because it might facilitate a more positive

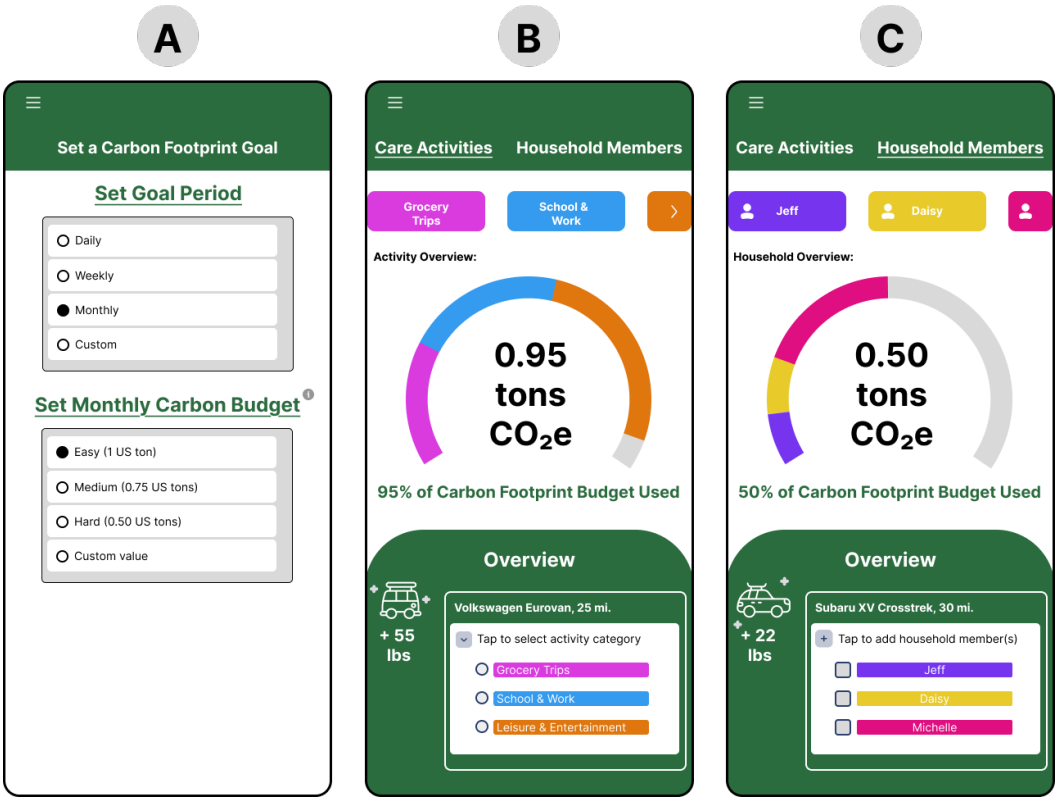


Fig. 2. Screens A-C depict design recommendation from 5.3.1 and from 5.2.1. **A.** Screen allows households to set a carbon footprint budget for a certain goal period and activities they choose to track as described in 5.3.1. **B.** Screen depicts an overview of annotated household mobility activities in the overview portion of the screen, which users can attribute to user defined care activity categories as depicted at the top of the screen (i.e., Grocery Trips, School & Work), as described in 5.2.1. Screen also shows a progress graph towards carbon budget, divided between various care activity categories. **C.** Screen depicts an overview of annotated household mobility activities in the overview portion of the screen, where users can attribute to certain household members as depicted at the top of the screen (i.e., Jeff, Daisy), as described in 5.2.1. Screen also shows a progress graph towards carbon budget, divided between contributions of the separate household members

experience for these people, incentivizing them to revisit engaging with this data. Conversely, we see carbon footprint data would be most applicable for adult household members.

Aside from limiting household costs, the emission budget approach allows the receivers of care to develop a baseline understanding of the energy requirements to fulfill their care needs. For instance, an EFI could log a child's school drop off routine then display the energy needs of other trips in relation to other mobility activities such as driving to a child's favorite park. The added benefit of this approach is it frames resources as limited, helping address the broader critiques of individually focused technologies as failing to acknowledge ecological limits [10, 59, 109]. Doing so also supports further reflection on the importance of care activities, such as what gym to go to, what activities can be completed using lower energy intensive transport options, as well as providing people with more insight into deciding on method of mobility required/preferred (car, walk, etc.)

to get an activity done. Furthermore, this approach has been explored in other sustainability work around data physicalizations and food consumption [65, 102], however this idea has yet to be extended in the domain of sustainable mobility. Aside from making sustainable decisions, developing household mobility budgets might help people in the home develop better data literacy outcomes, which has been suggested in prior self-tracking studies on creating more meaningful, personal tracking experiences [7, 16, 57, 128]. Moreover, this approach, might help households develop important collaborative skills needed to discuss sustainable practices in the home, such as communication, compromise, and co-reflection as demonstrated in prior work in EFIs [100, 120] and family information systems [63, 98]. Another strength of care activity budgets is that it supports households in working towards a clear recognizable goal. For example, a household might decide on becoming more environmentally conscious and want to reduce their carbon footprint from transportation from 14 tons CO_2/year, the U.S. national average, annually for households [14], to 12 tons CO_2/year. Having a numerical carbon footprint value might mobilize households in making decisions to stay under this value. Moreover, goal setting and migration has been repeatedly highlighted in self tracking work as a method of staying involved in personal data [24, 25].

6 Conclusion

Through this study, we contribute an understanding of how people in households collectively negotiate their sustainable transport decisions in their daily lives. Our findings indicate that roles and responsibilities related to household functioning shape individual family members' contributions to household emissions. To address this, we suggest that future systems incorporate annotation features which can potentially make care work in the home more visible, opening up a dialog for the negotiation of roles and tasks, in addition to sustainable mobility practices. We also highlight that future systems account for diverse environmental values and interests that may exist within a home, through providing conversational prompts. Doing so, might help households come together to reconfigure their definitions of what is considered 'good' in the sphere of sustainable mobility care related activities. Lastly, we recommend that future systems should be supported through care activity budgets to support goal-oriented reflection and negotiation of sustainable mobility data. These suggestions call for eco-feedback interfaces that move beyond the individual and are situated in a care context. By designing with household care in mind, as a community we will be better equipped to critically reflect on how environmental data is represented, shared, and acted upon.

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