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Assessing the Intent and Effectiveness of Carbon Footprint Calculators

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Abstract. In the context of addressing global warming issues, one of the possible approaches is to provide individuals with tools that support change toward greener practices, as for example around commuting. This paper illustrates a study that we conducted on the effectiveness of self-tracking of commuting data where participants received daily feedback on the financial costs and CO_2 emissions associated to their mobility practices. In the results, we describe situations where users do not accept the data and the models utilized to represent them, highlighting a limitation that diary instruments (and underlying models) of this type would have in supporting people to question and possibly change their mobility choices. On the basis of the study findings, we also describe a new model aimed at overcoming some of the limitations that the study showed, in particular by better connecting the individual environmental impact with the collective one.

Introduction

Global warming is a topic that raises many concerns at all levels in society. In response to these concerns the HCI research community has been involved in looking for solutions, especially in the area of limiting the impact of human activities on the environment (Bates *et al.,* 2018; DiSalvo *et al.,* 2010; Knowles *et al.,* 2018; Silberman *et al.,* 2014) and promoting change of practices to become more sustainable (Froehlich *et al.,* 2009; Froehlich *et al.,* 2010). While we are aware that the Sustainable HCI community has raised questions about the effectiveness of addressing the global warming problem through individual level actions (Csutora 2012; Knowles *et al.,* 2018), it is also the case that there is a portion of the population who shows a willingness to better understand their personal footprint in order to engage in concrete actions to reduce and limit their environmental impact (Dolnicar *et al.*, 2008; McKercher *et al.*, 2010). In parallel, while sparse and country dependent, we are also aware of public initiatives directed toward sensitizing the population around environmental topics and providing incentives to change them.

In this context, in past work we started to study what role work organizations may play in being facilitators of awareness and change in domains like mobility and specifically commuting (Castellani *et al.*, 2014; Castellani *et al.*, 2016). More recently, we organized a follow up study, presented in this paper, where we wanted to address a group of users interested in assessing and possibly adjusting their commuting impact through the use of travel diaries. We setup a study with two main objectives.

The first objective was to further refine our understanding of how people commute using different modes of transport, how they choose among those, what the reasons are behind their choices, and what are the perceived advantages and constraints associated to each means. Our expectations were that having a better understanding of the decision-making process could inform the design of a more successful tool to incentivize commuters to be more conscious about their mobility practices. The second objective of the study was to test the usefulness and legibility of a standard model to track and measure financial costs and CO_2 emissions related to commuting, and to understand what would be the impact of using a travel diary in the decision process and in support of change behavior practices.

We targeted specifically financial costs and CO_2 emissions due to commuting as these quantities are at the same time hard to compute accurately for people and can have a relative strong impact on decision making for taking one or another means of transport. In order to be able to compare the understanding with the perception of the usage of several means of transport adopted for commuting, we focused the study on users that tended to use different means of transport for a similar trip. For participants using only the car or only the bus to go to work, the feedback in terms of costs and CO_2 emissions would have been the same every day automatically reducing the possibility for reflection offered by the self-tracking exercise.

Through the analysis of the interviews with the participants and their diaries we aimed to gather knowledge on how people reasoned about the different modes of transport and how they made their decisions. Moreover, we wanted to get some understanding of if and how the self-reflection on their commuting patterns may impact their future choice of means of transport, and also how each means of transport was understood with respect to its environmental impact. What we did not really expect though was to have to face another aspect of the study, i.e. that a pretty standard way to compute the costs and CO_2 emissions associated to commuting would have been questioned in the way it was during the interviews.

This is aligned with what Remy and colleagues say, that there is more than usability to be evaluated when it comes to Sustainable HCI (Remy, 2018). Such a central aspect of a mobility self-tracking system became then the major focus of the subsequent analysis. It is the kind of serendipitous finding that may appear in a qualitative research and that in our case took over all other findings coming from the study (Corbin *et al.*, 2014; Rivoal and Salazar, 2013). These observations then led us to the design of a new model aimed at overcoming the limitations we found. In particular, we eventually proposed a new way to compute figures that participants of the study perceived to be both fairer, with respect to their impact on the environment, and more accurate.

In this paper we will focus on presenting the results that relate to how users dealt with the proposed model and the consequent design implications that we drew from the study.

Related Work and Study Objectives

The use of personal informatics, also referred as quantified-self or self-tracking, is today made possible by the variety of tools and connected objects that are available to individuals and has been widely analyzed in the HCI research community (Epstein *et al.*, 2015; Li *et al.*, 2010; Rooksby *et al.*, 2014). One recognized use of personal informatics is to support change management (Kefalidou *et al.*, 2015; Kersten-van Dijk *et al.*, 2017). The link between self-tracking and change management is in the reflexive position that users can adopt regarding their behaviors (Ptakauskaite *et al.*, 2018). Based on the collected data and on the change the user wants to achieve, personal informatics support the user by tracking progress toward a desired direction.

Many studies have focused on activity trackers that track the number of steps, the quality of sleep, the heart pulsation or burned calories. The majority of self-tracking practices target the domain of health and well-being (Choe *et al.*, 2014), where models are fairly simple: a step is a step, the quality of sleep computed as presence or absence of movements during the night, the number of heart pulsations, and the number of calories burned. Despite the required low level of knowledge and relative simplicity of the underlying models, some studies have already reported the difficulty that users may encounter when having to interpret the figures provided by the trackers (Coulter *et al.*, 2008; Herrmann *et al.*, 2018; Puussaar *et al.*, 2017).

When moving to the sustainable mobility domain, we can expect the difficulty of people in relating to the numbers to even increase, since the phenomena are much more complex and difficult to reduce. If a user commutes with her car every day, how are we going to compute a fixed amount of money that is spent each day to go to work by driving a car? Should we include the initial cost of acquiring a car? The annual insurance fee? The costs of maintenance? If yes, how should it be integrated in the daily cost of driving a car to work? Then we should also add the cost associated to the fuel used for that specific trip, which is indeed the simplest thing to do when thinking of costs of commuting with a car. For the computation of CO2 emissions, in a similar way, many questions are open. How should we calculate the CO2 emissions of someone taking the bus? Should we take into account the number of passengers in the bus on that specific day? Or make an estimation with an average?

Current online tools for eco-feedback on mobility are based on disaggregated data among the various means of transport (in Ref. Carbon Footprint calculators). This means that for any mode of transport and a given distance, there is a cost and an amount of CO2 emission that is associated (for instance an average CO2 emission per distance and per passenger for public transport). The disaggregation of the data is a useful starting point as it has shown to help to support the understanding of the behaviors in settings like the smart grid (Froehlich *et al.*, 2011). However, as we will see through the results of our study, the use of disaggregated data coming straight from CO2 calculators is not enough to represent commuting in a way that users can relate to. As the computation is complex and is based on a range of factors (owning a car, having a public transport monthly pass, ride-sharing), it is difficult for a person to construct an accurate personal estimation of the impact of commuting practices (in terms of financial costs or CO2 emissions) (Betz *et al.*, 2010; Brazil and Caulfield, 2014; Waygood and Avineri, 2011).

This complexity translated by an absence of baseline and a possible under or over estimation regarding self-practices may lead to situations where a user may not understand or accept the data provided by the tracker. These difficulties, as we will see, may go beyond the difficulties highlighted in other studies of making data understandable through visualization and representation (Choe *et al.*, 2014 ; Rapp and Cena, 2016). The difficulties that we found are rather core to the definition of the model underlying the computation of costs and CO2 emissions due to commuting. There are studies on tools supporting greener mobility practices (Bie *et al.*, 2012; Bothos *et al.*, 2014; Bucher *et al.*, 2016; Gabrielli *et al.*, 2013; Jylhä *et al.*, 2013), but to the best of our knowledge, none of them details and discusses the model underlying the computation. This work aims at contributing to the body of knowledge about how people reason in practice about this type of data. Specifically, with this work, we want to provide the following contributions:

i) to highlight how, when it comes to self-tracking of abstract computed data, the choices of, what data to use, made by the underlying model impact the acceptability of the figures provided;

ii) to propose a more suited model for self-tracking of CO2 emissions and costs associated to commuting.

Methods and Settings

In order to study how people understand and accept figures of CO_2 emissions and costs due to commuting, a diary study has been conducted. We have chosen this methodology (Riemann, 1993) as it is difficult to gather information on commuting practices through observation over a long period of time. The first part of the study occurred over a period of 4 months in summer 2015 and the second part in 2016. The study was undertaken in a French metropolis of 700 000 inhabitants which is a quite large city with characteristics in terms of transport infrastructure, mobility habits and needs of its inhabitants, etc., that may differ quite a lot with respect to a megalopolis or a small town. For example, in this town there is a well-developed public transport network available to its citizens (which is not necessarily the case for example in small towns). And this can have an influence on the way the participants to the study organized their commuting.

Participants

We recruited a group of participants from the city we are located in. It was important to be close to the participants in order to have a grounded understanding of the commuting context in the area, of the public transport options available, and to be able to facilitate the interviews during the study. The recruitment was done through a snowball sampling and ten participants took part in our research. This sample size is quite common in qualitative studies that targets to get a fine-grained understanding of a specific and complex question (Li *et al.*, 2012; Rapp and Cena, 2016; Thudt *et al.*, 2018). The ages varied from 27 to 56. Our participants were all professionals, qualified as engineers, computer scientists, doctors, technicians, school teachers and sales assistants.

The recruited participants all already had a commuting routine in place such that over a month they would use more than only one means of transport to go to work. Our objective with this constraint was to be able to provide participants with feedback on their behaviors looking at the different figures according to the various means of transport. The objective was to observe how participants would understand their environmental and financial impact related to commuting. This constraint was quite strong and made the recruitment process more difficult and longer than expected.

The home-work distance for the participants varied between 2.1km and 39.6km with an average of 15.1km (SD:13.9). The participants lived quite close to their workplace and our sample is consequently quite different from the typical

commuter average home-workplace distance in France that in 2004 was 25.9 km (Baccaïni *et al.*, 2007).
Table 1 shows the various means of transport used by the participants.

Table 1. Means of transport and Home-Work distance (km)

ID	Means of transport for commuting	Home-Work Distance (km)
P1	Tramway, bike, car	3.1
P2	Bike, bus, moped	6.7
P3	Tramway, car	3.4
P4	Bike, car	5.4
P5	Car-sharing, bus, car	27.6
P6	Bus, bike, car, car-sharing	18.5
P7	Bike, tramway, car	2.1
P8	Bike, train, car-sharing	39.6
P9	Car, car-sharing, bus	37.5
P10	Bike, bus, kick scooter, car	7.4

Procedure

The study was performed in two iterations. The first iteration is the diary study which was divided into three main steps. The first one was a face-to-face semi-directed interview with the participants where they described precisely their commuting practices: the means of transport used, the reasons for choosing a given means of transport on a given day, the preferences that they may have for one or another means of transport and the constraints they may have in their professional or personal lives according to commuting. The objective was to gain a global understanding of commuting practices. We also collected the exact path they used and all specific information on their personal car or moped (type, brand, year of construction, type of combustible). We also gathered information about possible goals associated to commuting, if they had any, such as: being able to read or do something else while commuting, reducing the financial cost of their commuting, increasing their physical activity, or limiting their environmental footprint.

During the second phase the participants filled a pen and paper diary during 20 working days. Each day, the participants had to indicate the date, the means of transport used that day, the reason why they made that choice and if anything pleasant or unpleasant occurred during the commuting. In the first interview, participants were asked if they would optionally share their diary with us every week in order to have weekly feedback of their practices. Even though many participants expressed enthusiasm regarding the proposal, only two of them exploited this possibility to receive weekly feedback. This relates to the extra work associated to collecting and managing the data (Lazar *et al.*, 2015). Nevertheless, all of them finished the study and produced a daily diary as requested. After the 20 days, the participants returned their diaries and we were then able to compute all the figures regarding the cost and CO_2 emissions of their commuting. The model underlying the computation is the Eco-calculator described in the next section.

The third part of the study was a second interview with the participants, where we provided them with a compacted view of their commuting practices over the 20 days, as presented in Figure 1. For each day (a cell in the table), we represent for the user the means of transport used to go to work (top left corner of the cell) and the means of transport to go back home (bottom right corner of the cell).

Figure 1 Compact representation of the commuting practices of P6 over the 20 days of diary study

We also shared with the participants a representation of the financial costs and CO_2 emissions for each day. Figure 2 shows an example of these representations for participant P6. All the figures produced on the participant's commuting was presented to the participants during interviews with all the required explanations in order to allow them to make sense of it.

The aim of that last interview was to assess if the exercise of keeping a diary on commuting practices had impacted the understanding of their practices and if any change had happened. The other goal of the second interview was to provide the participants with the compiled figures and then to discuss with them if and how those figures had made them think about their commuting practices and choices.

The second iteration used the exact same data from the participant's diaries to provide new figures of the financial costs and CO_2 emissions based on a new model designed to overcome the difficulties identified in the findings. The new model is also described in the findings. In order to question the new figures obtained and gather the feedback of the participants, we organized another round of interviews, only with the participants whose figures were impacted by the model. In our case it was all the participants who had use public transport during their 20 commuting days.

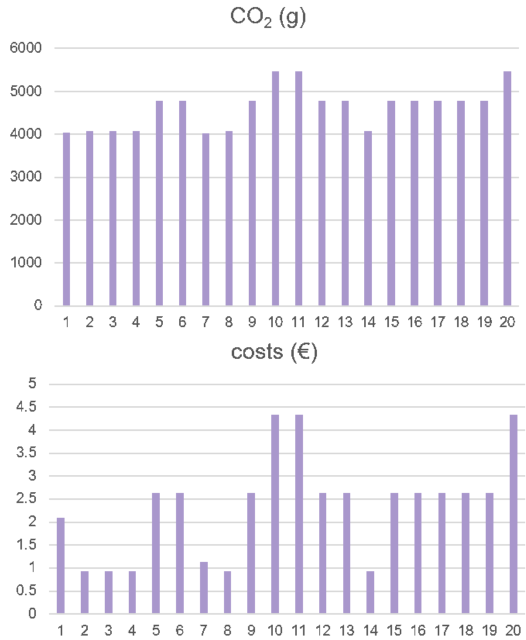

Figure 2. Feedback on the cost and CO2 emissions from the eco-calculator model due to commuting for P6

The eco-calculator

The computation of the financial cost and CO_2 emission figures was manually performed and based on typical carbon footprint calculators publicly available at the time of the study (in Ref., Carbon Footprint Calculator). The details are presented below.

For the trips with cars or moped: the cost estimation only considers the fuel consumption for the trip, meaning that for each travel, the computation is the distance covered (km) times the cost of a liter of fuel (€/L) times the average fuel consumption for that specific car or moped (L/km).

For the CO_2 emission, the computation is the distance covered (km) times the average CO_2 emission for that specific car or moped (g/km).

If participants did car-sharing, the figures computed for the cost and CO_2 emission were divided by the number of passengers for the travel.

For the trips with public means of transport, the cost is either the cost of a ticket or the monthly pass and the CO_2 emission is computed as the average CO_2 emission for one passenger (g/km)[1] times the distance covered (km). For commuting using bike, kick scooter or walking, the costs and the CO_2 emissions are zero.

Finally, if the participant payed for a monthly transit pass, its cost was distributed over the 20 working days of the month.

Data Collection and Analysis

We audio-recorded all interviews and collected participants' diary entries. All the interviews were entirely transcribed and analyzed together with the diaries. We identified themes using a thematic analysis (Braun and Clarke, 2006). For this study, we inductively identified themes starting from the data trying to find commonalities rather than having a pre-existing representation of understanding. We describe our findings in next section.

Findings

Feedback from the interviews revealed situations where the data put the user at unease with respect to their own practices. Part of it relates to issues of understanding data and other aspects are rather linked to the acceptance of data. We do not want to develop this type of feedback in this paper, but rather to focus on a major outcome of the study which is the inadequacy of the intent behind the model, here to promote greener means of transport, and the figures provided to the participants.

Inadequacy between the model and its intent

The main objective of simulating a tool tracking commuting practices with a diary was to get a first evaluation of what could be its role, if any, in incentivizing users to use greener means of transport. It is therefore critical that the data is not only understandable, as discussed in the previous section, but also perceived as fair. Tracking data about CO2 emissions singles individuals and families out and questions their habits (and potentially their privileges) vis-à-vis a global problem. But to do so effectively, the model has to be able to properly contextualize the behavior of individuals and family units within the overall environmental impact of the collective (the city or metropolitan area, the country, etc.).

P5 lives more than 25 km from work and is used to commute either with a combination of car-sharing and bus, or by car solo, or by car-sharing. Because all options involve the use of the car, P5 and his partner were really concerned by their environmental footprint:

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1 These figures come from the Carbon Footprint Calculator (In Ref. Carbon Footprint Calculator, first website) with the figures at the time of the study (2015) being for one passenger: 103,3g/km of CO_2 for the bus and 3.1g/km of CO_2 for the tramway.

"The main objective was to reduce costs, in terms of car mileage, petrol consumption, etc. Because we are both committed to being more environmentally conscious, and we said to ourselves that it amounts to having two cars less on the road, we decided to take the bus" (**P5**)

The solution they had chosen (Figure 3) was to have a main option with car-sharing from home to the bus-stop and then taking a bus. This meant that on the way back they had to coordinate to take the bus at the same time and then go back home together with the car. They had a second option, that was to go to work and back home with a car doing car-sharing. They resorted to this second option when one of them planned to use the car for some specific needs during the day.

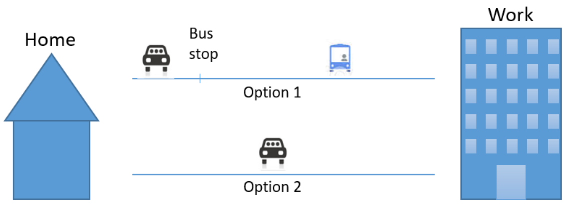

Figure 3. Options of commuting for P5

According to the eco-calculator model used in the study, the greener option was option 2. The calculator was showing that there were less CO2 emissions with option 2 than with option 1. When the researcher explained that to P5, he said:

"ah this is disappointing" (**P5**)

then he tried to understand by guessing that emission should have been a more global one:

"This is just for me, but in the bus, we are not alone" (**P5**)

The researcher explained again how the emissions of CO2 for public transport were computed (each passenger on a bus emits 103,3 g of CO2 per km). However, after the explanation, the questioning was still in place:

"which would mean that car-sharing would produce less CO2 than a bus even when it is full?" (**P5**)

This result was really surprising for P5 because it did not comply with the reality of facts as he perceived them: when P5 chose option 1, the car was used only on a little portion of the trip and then he took the bus. When P5 chose option 2 the car was used for the whole trip and there was also the bus circulating. So, from his perspective, option 1 cannot correspond to a higher emission of CO2 than for option 2 because there is one less car on the road between the bus stop and the workplace.

Similarly, P9 was surprised:

"Ah… I emitted less CO_2 in [car-sharing than in bus]" (**P9**)

Three other participants (P2, P6, P10) faced similar situations where for instance a trip using car-sharing or moped was causing a lower or almost equivalent in quantity CO2 emission than a trip using public transport. This was not the representation of a "greener means of transport" according to what the participant had in mind.

To go further, P10 added:

"yeah the thing about the bus is that you are not responsible for the itinerary, you use something that is there regardless and you do not directly emit anything." (**P10**)

Which expressed the gap between a global representation this participant had in opposition to a model that was providing daily feedback at an individual level.

Combining individual and shared responsibility in a new model

As mentioned in the introduction to this paper, one of the potential issues with this type of tool is that it is contentious whether that of individual behavior is the level where environmental questions can be effectively addressed. But when it comes to vehicle related CO_2 emissions, whether individuals decide to use public transport or greener forms of transportation, and on the basis of what information, is a matter of public policy and concern. And the fact is that the type of confusion over feedback provided by eco-calculators that we encountered in this study is particularly unhelpful when it comes to properly contextualizing individual behavior within a practice (commuting) that depends on public infrastructure and resources and is deeply impacted by choices made about them (for example, where and how to develop public transport, what incentives or disincentives are provided for the use of cars or other means of transport, public policies impacting cost of ownership, etc).

In order to provide feedback that more clearly contextualizes individual measurements and choices on costs and CO2, emissions within a public transport network, we have defined a model that explicitly considers and illustrates both urban community and individual related costs, and for the latter it encapsulates the different types of costs. The objectives were to increase accuracy regarding the real financial costs and CO2 emissions and fairness regarding the way people think about their commuting practices, and finally to have a model that can help to encourage the adoption of more sustainable means of transport. The model considers three types of costs (or CO_2 emissions): the community fixed costs, the individual fixed costs, and the individual variable costs.

Community fixed costs (CFC)

Community fixed costs can be computed mostly by using information provided by some public documents produced by urban area governments. Two types of information are required: information about the population and information about transport spending. For the first we decided to take as a reference the whole population living in the area, typically known from census data.

We did not make any distinction among commuters on the basis of their activities or home location as all of them can be at any point a user of public transport. For information about transport spending, we considered all public money spending associated to transportation. This included both road/infrastructure work and public transit sponsorship. For the CO_2 emission we considered only the information on the public transit. From these two figures we simply divided the total cost per number of inhabitants and per day in the year to obtain the community fixed costs.

Individual fixed costs (IFC)

Individual fixed costs are associated with two elements: the ownership of vehicles and the ownership of monthly or annual transit or parking passes. Ownership of a vehicle includes the cost of its acquisition, maintenance, and the insurance fee. For the figures used in the study, we collected all the required information listed for community fixed costs and individual fixed costs from a public document (SMTC, 2013) which is mandatorily produced by each French urban area larger than 100 thousand inhabitants. We have not included in our model any IFC CO_2 emissions but we could consider the CO_2 emissions of the production of a car or a bike.

Individual variable costs (IVC)

Individual variable costs are the costs that are generated when travelling in addition to the individual fixed costs. For financial costs these include the individual payments that are done when using a transport service, transit, taxi, parking car/bike rental, and the cost of the fuel consumed when using a private car. For CO_2 costs: the use of a private vehicle (including a taxi) accounts for the whole vehicle CO_2 emissions if used in single occupancy mode and divided by the number of occupants otherwise. Usage of transit services does not account for extra CO_2 emission since those are already included in the community fixed costs.

Figure 4 shows the new versions of the figures for participant P6 computed using the new model. When comparing with Figure 2 showing the figures for P6 with the first model, we directly see for days 2, 3, and 4 that P6 is using transit as she has no additional CO_2 emissions besides the CFC ones and there is no additional cost besides the CFC and IFC ones.

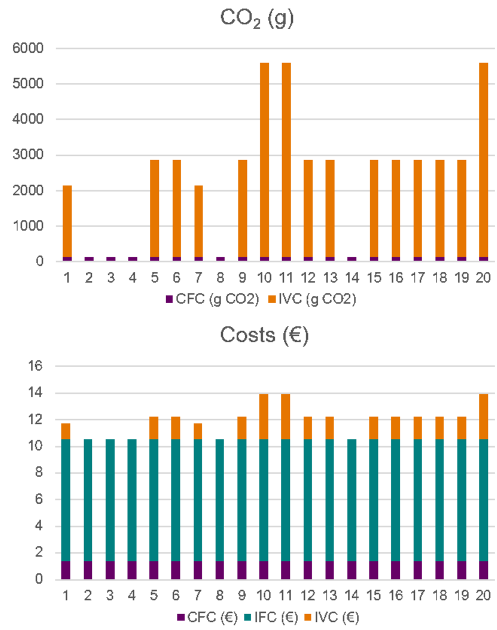

Figure 4. Feedback on the cost and CO2 emissions from the new model associated to commuting for participant P6

Feedback on the new model

The three types of costs illustrated in the new model can be applied to compute both financial costs and CO_2 emissions. We re-computed the data of all participants with the new model (as the second iteration of the study described in Material and Methods) and decided to conduct interviews using the new figures with the participants for whom it made a real change from the figures obtained with the first eco-calculator model (P2, P3, P5, P6 and P10). These were in fact the participants who used public transports during the data collection. All the interviews were entirely transcribed. During the interviews we were able to gather positive feedback on the new model. P2, P5 and P6 found that the new model was better at accounting for pollution issues. P2 and P3 identified that the costs computation was fairer and that it was relevant to have such notions. For P5 and P6, it was better incentivizing usage of public transit.

As a general conclusion, all the participants involved in this iteration with the new model found it to be more relevant, more accurate, fairer, and more convincing than the previous one.

We observed that the new model better represented the impact of user's choices and the possible impact of changes. This was obtained because costs and CO_2 emissions were organized showing both short-term and long-term impact of the user's practices or habits. The fact that there is public transport in a city depends on the policies of a town and can be changed eventually by participating to elections. The cost of having a car is based on the decision of a user, at one point in time, to buy a car. This decision has a financial impact every day. Finally, the CO2 emissions due to a specific trip with a car is based on the choice on a given day to take the car instead of riding a bike, taking the bus or walking. In the end, it appeared meaningful to differentiate the data, not according to the means of transport (as in the eco-calculator), but rather according to the type of type of choice made by the user, where (s)he can indeed act.

Discussion

The intent behind the model

A main reason why the eco-calculator model was leading to inconsistencies was that the outcome of the calculation appeared to contradict the intent of the model itself (Lockton *et al.,* 2016). The intent of the eco-calculator was to support the adoption of greener practices. What appeared as an outcome was that, for several participants, the use of the bus led to more CO_2 emissions than car-sharing or moped. As P5 said:

"In that case I should stop taking the bus." (**P5**)

This conclusion would be very likely in opposition to what public authorities and common sense perceive as green transportation practices. Either the model inadequately computes the CO_2 emissions for feedback at an individual level, or car-sharing is really less polluting than public transportation and in that case it would be worth to acknowledge that and act accordingly.

In a similar fashion, we observed during the interviews side-effects from the new computing model. The intent behind the improved commuting model was both to avoid the sources of misunderstanding that we identified when using the first model and to provide figures showing to people the lower impact of some means of transport, like public transport or walking, cycling, or kick scooters. As this model makes visible the daily cost of ownership of a car, it might support users to more clearly consider the opportunity of owning a car or not. An unwanted side-effect of this kind of model is well described by P2:

"that is what I should tell myself, even when I take the bicycle I pay for the insurance of the car so it is not profitable to use my bicycle" (**P2**)

Behind any model there is an intent and possible unwanted side-effects.

Conclusion

The main outcome of this work, is that a model better tailored to provide feedback on costs and CO_2 emissions in comparison to currently used models, allows users to get feedback that contextualizes their behaviors. It is beneficial to represent in the figures the relationship collective and individual responsibilities when it comes to commuting. Indeed, commuting requires to make choices upon individual options of means of transports, abilities, preferences in the context of a community that offers infrastructure such as public transport, cycle paths, roads etc. What the participants appreciated in the new model is that even though there is a relative high level of abstraction, this model was able to capture the complexity of the question and to reallocate the various levels of responsibility to make it fairer.

We believe that this work and the resulting new model can be inspiring for the quantified-self community about ways to answer to the need to better contextualize tracked data (Boulard-Masson *et al.*, 2018).

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