BEHAVE 2023
7th European Conference on Behaviour Change and Energy Efficiency
Maastricht, 28-29 November 2023

Nudging households for energy savings via smartphone apps and web portals: an empirical study

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Keywords: Nudging interventions, End-user behaviour, Energy efficiency, Smartphone app, Data analytics

Abstract

In this paper, we report evidence collected in the context of the Horizon 2020 NUDGE project about the effectiveness of digital tools such as smartphone apps and web portals to realize nudging interventions towards different energy efficiency goals: from the reduction of heating energy and electricity to the increase of self-consumption in energy prosumer households. We analyse recorded events from the interaction of participants with those tools in the context of three different pilot experiments.

We first assess the level of end user engagement with the apps and the portal, counting the number of distinct days that they interact with them. We find it to be highly heterogeneous, with up to 25% of participants in the Greek pilot and 12% in the Portuguese pilot not using the mobile app at all, and the rest forming three distinct groups of low, medium and high engagement. The interaction with the apps almost always lasts fractions of a minute and involves accessing a few app screens. We next turn to the actual users' exposure to the nudging features of the digital tools to find out that high percentages of users (up to 50%) exhibit zero or very occasional exposure to the app screens that implement nudges. The mobile app users, in particular, can be grouped into four clusters depending on the level of engagement with the app and their exposure to its nudging features. Disappointingly, more than half the pilot participants belong to the cluster combining low engagement with low exposure to nudging. Combining these data with self-statements of participants in post-intervention surveys, we find no significant correlation between the level of nudging exposure and the (self-stated) motivation/ intentions to save energy.

1. INTRODUCTION

The recent European energy crisis due to the war in Ukraine reinforced the value of energy savings and energy efficiency (IEA, 2022), pointing to the need for effective policies that could bring about sustainable behavioural change in this respect. Emphasis has been given to residential energy consumers (households) and how behavioural interventions could promote the energy efficiency goal (McAndrew *et al*., 2021). Nudging (Thaler and Sunstein, 2008) has been viewed as a promising path to deliver behavioural interventions. Prescribing a distinct set of choice architecture techniques for soliciting socially desirable behaviours and discouraging/confronting non-desirable ones, nudging has found broad applicability across different behavioural domains with several positive results (Mertens *et al*., 2022). With respect to energy efficiency, in particular, positive nudging effects are recorded in (Schleich *et al.*, 2013) (Frederiks *et al.*, 2015), (Kroll *et al.,* 2019) to mention but a few.

As most people have incorporated mobile phones and the world wide web in their regular routine, relying on mobile applications (apps) and web platforms for various daily activities, it is almost inevitable to use these tools to digitally deliver interventions to energy consumers (Mirsch, Lehrer & Jung, 2018; Weinmann et al., 2016). The spread of smart meter usage and the capability of mobile apps and web portals to monitor and visualize energy consumption data only strengthens the argument. The idea is that recruiting those digital tools, interventions can be more direct, more timely, and eventually more effective. Indeed, in (Fan et al., 2017; Kroll et al., 2019) end users are nudged to reduce their energy consumption by getting feedback about it through mobile applications; and (Rafsanjani et al., 2020) promote reminders on the smartphone as effective digital nudging practice towards energy saving. A similar concept of feedback nudges is proposed in (Fan et al., 2017; Kroll et al., 2019), where users are informed about their energy consumption through mobile applications. Furthermore, according to (Frederiks et al., 2015; Rafsanjani et al., 2020), reminders can also be an effective nudge for consumers to adopt a better energy-saving approach.

Whereas the existence and size of the nudging interventions effect is under debate in literature (Mertens et al.; Maier et al., 2022), in this work we take one step back and ask to what extent end users get engaged with mobile apps and web portals and actually get exposed to the interventions that are delivered through them. We argue that having a clear view about this engagement is an absolute prerequisite for correctly reasoning about the (non) effectiveness of an intervention. To this end, we work with data collected from three pilot experiments (pilots), carried out in Germany, Greece and Portugal, respectively, as part of the European Horizon 2020 research project NUDGE[1] which designs and delivers nudging interventions towards different energy efficiency goals leveraging mobile apps and web platforms. The data are logs of various events from the interaction of end users with the mobile apps and web platforms used in the pilots. Our two main goals are to assess the level of end user engagement with the apps and the portal and the extent to which they get exposed to their nudging features. Interestingly, there is a considerable number of users, in particular for the two apps, who are not using the apps at all (25% in the Greek and 12% in the Portuguese pilot), whereas the engagement with

[1] https://www.nudgeproject.eu

the portal is better in the German pilot. Then, those who do use the app differ broadly as to how often they use the app and how much they get exposed to its nudging screens/pages. We could identify four clusters of pilot participants considering these two features alone, i.e., engagement and nudge exposure. We correlate the findings from the app data with the responses of pilot participants to survey questions about their motivation and intention to save energy. These self-statements are a (weak) measure of the nudge effects[2] and offer first insights to whether the frequency of user interaction with the application/portal correlates with the nudging effect and could qualify as a predictor for it. Regarding app usage, differences occur based on the pilot and the intervention period. However, three groups (low/medium/high) of application use are identified for the three pilots. Furthermore, users are occasionally exposed to nudges, approximately 2 times per week.

The rest of the paper is organized as follows. Section 2 presents the datasets that were made available from the pilot experiments (pilots) in the three countries and the type of nudges applied to their participants. Section 3 presents and discusses the results from the analysis of mobile app data. Finally, section 4 concludes our work and outlines future work.

2. NUDGING INTERVENTIONS AND DATASETS

Three pilot experiments, in Greece, Portugal, and Germany, provided the data for the analysis we report in the sequel. Each pilot addresses a different aspect of energy efficiency and pursues it by means of nudging interventions ("nudges"). Specifically, the Greek pilot addresses gas consumption for heating purposes, the German pilot focuses on increasing the consumption of self-generated electricity from the households' photovoltaic panels and the Portuguese one treats electricity consumption in conjunction with indoor air quality.

The pilot participants are exposed to different nudges through smartphone applications (mobile apps) and web portal. For the Greek (GR) and German (DE) pilots, existing commercial-use smartphone applications were adapted to realize the nudging interventions, while the mobile app for the Portuguese (PT) pilot was built from scratch to fit the experimentation requirements. Furthermore, for the DE pilot, users have access to a web portal, where they can be informed about their energy consumption based on real time data. Although the actual types of interventions vary across the three pilots, all three of them follow the rough timeline in Figure 1. Each pilot includes three nudging intervention periods, during which the pilot participants are exposed to interventions, the pre-intervention phase that precedes the launch of the first intervention, and the post-intervention period following the completion of the last intervention. Wash-out periods of no intervention activity typically alternate with intervention periods.

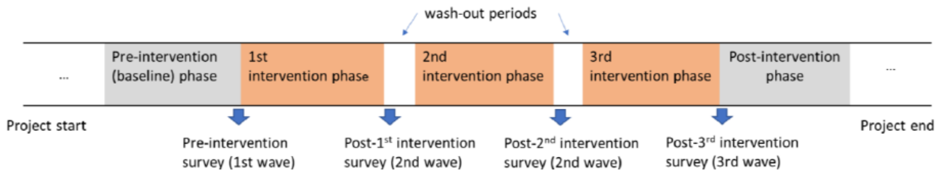
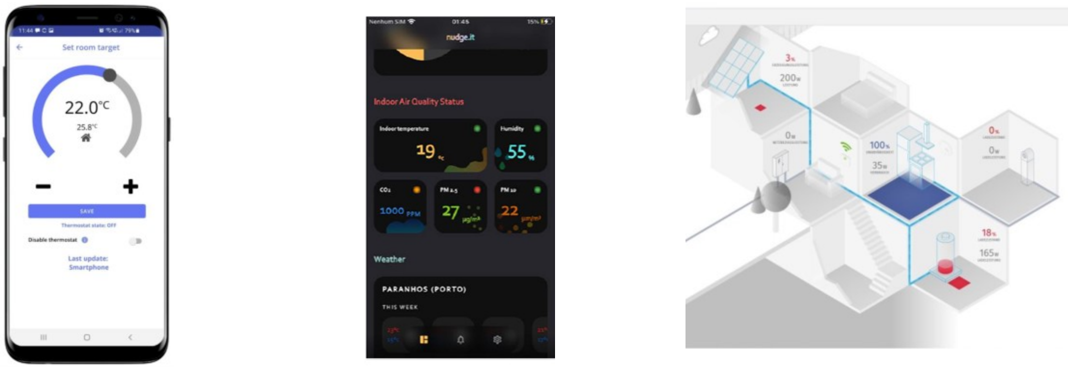


Figure 1. Common timeline of the nudging interventions for the three pilots.

[2] The ultimate assessment of nudging effects relies on sensor data, refer to the companion paper (Kesselring *et al.*, 2023)

All pilots collect three types of datasets. First, four waves of surveys are filled out by the pilot participants before the first intervention and after each one of them. Then, specific events out of the interaction of pilot participants with the mobile apps are recorded, e.g., the launch of the app and the exposure to different app screens. Finally, gas/electricity consumption and production (for the DE pilot) data, together with other types of pilot-specific measurement data, such as temperature or concentration of particles in the air, are continuously being logged by smart meters and other sensors at periods ranging from 1 min to 15 mins depending on the actual measurement. In this paper, we analyse the first two types of data sets, namely survey data and mobile app data. The analysis of the energy consumption data from smart devices is the subject of a companion paper (Kesselring et al., 2023). In the following sub-sections, we describe the nudging interventions that were mediated through the smartphone apps in each pilot and the collected datasets from each one of them.



(a) DOMX app (GR pilot) (b) nudge.it app (PT pilot) (c) Web portal (DE pilot)

Figure 2. Mobile apps and web portal interface used in the three NUDGE pilots.

2.1 Greek pilot on gas consumption for heating purposes

2.1.1 Mobile app and nudging interventions

The app of the GR pilot (Fig. 2(a)), called "DOMX", is available through the app stores for Android and iOS. The app enables remote monitoring and control of the target temperature at the gas boiler thermostat, depending on the user's heating demand, comfort limits, and personal preferences.

Each of the three nudges is implemented in the DOMX app as one or more application screens. Nudge 1 is a feedback and awareness nudge, providing information and statistics about the user's energy consumption over time. Nudge 2 is a confrontation nudge that presents users with preventive just-in-time (JIT) prompts each time they are about to perform an action that would increase energy consumption. Finally, nudge 3 is realized through two types of push notifications, one presenting an energy-saving tip and another one congratulating end-users for proper energy consumption practices. These two notifications are also made available as messages on a separate screen.

2.1.2 Participation and datasets

A total of 100 households participated in the GR pilot. The first intervention period lasted between January 2022 and March 2022 with the participation of n = 47 households. The second intervention took place between December 2022 and January 2023 with n = 100 households and, immediately afterwards, the third one was carried out between February and March 2023, also with n = 100 households. The three post-intervention surveys were filled out by 39, 80, 73 household representatives, respectively. Mobile app data for the GR pilot have been made available for the second and third intervention periods (we could not obtain data from the first intervention period due to technical reasons).

2.2 Portuguese pilot on electricity consumption

2.2.1 Mobile app and nudging interventions

The mobile app developed for the PT pilot is called "nudge.it" (Fig. 2(b)). It was first released in March 2022, and it has since been available through the Android and iOS app stores.

The first nudge involved a dashboard with bars and a circular graph representing energy consumption of the user during selected time periods. The second nudge targeted the indoor air quality (IAQ) of each household. Users were exposed to information about IAQ indicators, e.g., CO2 levels, and push notifications when concentrations of CO2 exceeded a health-alarming threshold. Finally, as part of the third nudge, users with a thermostat received a notification to reduce the space heating temperature and all users, including those without a thermostat, were exposed to a dashboard containing information about their energy consumption.

2.2.2 Participation and datasets

101 households were monitored throughout the experimentation period, from June 2022 till March 2023. Participants were randomly assigned into two equal-size groups (group 0: n= 51, group 1: n= 50) and were alternately exposed to nudges during each intervention period. The first intervention period lasted from 3 June 2022 to 9 September 2022, with an intervention-free two-week period from 16 to 28 July 2022. After a two-month wash-out period, the second intervention took place from mid-November 2022 till end January 2023, with an intervention-free two-week period from 15 to 26 December 2022. The third intervention was launched on January 25th, 2023, and lasted till the end of March 2023, with an intervention-free week 20-27 February 2023. Mobile app data for the PT pilot have been made available for all intervention periods except for the second half of the 3rd intervention period[3]. The post-intervention surveys were filled out by 71, 70, and 82 participants, respectively. 89, 86 and 78 households interacted at least once with the app during the three intervention periods, respectively.

2.3 German pilot on self-consumption

2.3.1 Web portal and nudging interventions

The web portal (Fig. 2(c)) provides an overview on the electricity flows within the household, especially tracking the level of self-consumption. For the first feedback-type nudge, a new dashboard was created with simple colour-enhanced indicators categorizing the participant's

[3] Indeed, mobile app data for the PT pilot is missing for the interval Feb 19th-end March, which means that we have data for the first 25 days of the 3rd intervention period.

current self-consumption level into acceptable (green) or unacceptable (red). As second nudge, a bar chart compared the participants' current self-consumption level to the one in previous months. Last, for the third nudge, a new energy-friendly charging mode was recommended as the default option for participants with controllable electric vehicles (EVs, n = 39). Once the setting is initially activated, before the first usage, the EV is charged with excess self-generated electricity. The participants can overrule the default charging mode by specifying a target state of charge by a specific departure time. Moreover, all users obtain aggregate information about the two previous nudges in the form of an energy report.

2.3.2 Participation and datasets

For the DE pilot, 111 households with photovoltaic panels monitored their simultaneous consumption and generation of electricity in a web portal. With the help of the web portal and its supporting information, the goal was to increase the share of consumption covered by self-generated electricity (i.e., self-consumption). The three nudges were implemented sequentially for alternating control and treatment groups, i.e., each nudge is first provided to group 1 (n =54), during the first half of the nudging period, and it is then removed from group 1 and provided to group 2 (n = 57) during the second half of the intervention period. Nudge 1 was implemented from April to mid-July 2022, nudge 2 from mid-July till mid-February 2023 and nudge 3 mid-February till mid-June 2023. Unfortunately, information on the interaction with the app/web portal is only available for nudges 2 and 3, with 105 and 106 participants, respectively, interacting at least once with it. The three post-intervention surveys were filled out by 86, 91 and 88 unique participants, respectively.

2.4 Summary of survey and mobile app/web portal data

Table 1 summarizes the availability of survey responses and data from the interaction of participants with the mobile app (GR, PT pilots) and the web portal (DE pilot). Mobile apps are used by more than 76% of the GR and PT pilot participants, with a higher average participation across the three interventions in the second case (in the order of 84%). Even higher (almost 95%) is the percentage of DE pilot participants who access the web portal.

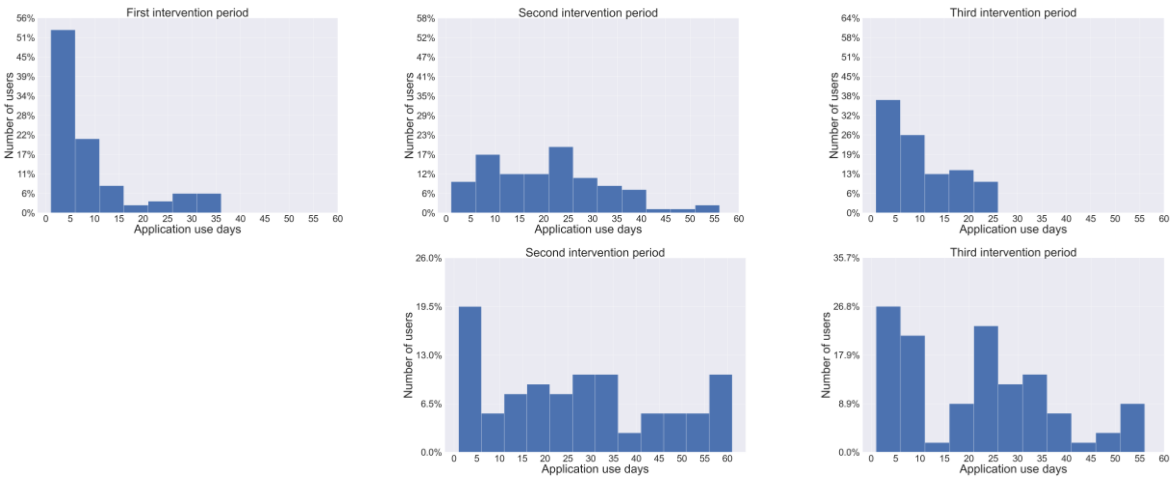
Table 1. Number of participants per pilot during the different intervention periods (n: represents the total population).

	1st Intervention		2nd Intervention		3rd Intervention	
Pilot	**Survey**	**App/portal**	**Survey**	**App/portal**	**Survey**	**App/portal**
GR (n=100)	39 (n = 47)	-	80	77	73	76
PT (n=101)	71	89	70	86	82	76
DE (n=111)	86	-	91	105	88	99

3. RESULTS

3.1 Use of digital nudging tools by pilot participants

A first question of interest is: ‘How frequently do the pilot participants interact with the mobile apps and the web portal?’ For the GR pilot (Fig. 3), in both intervention periods, we witnessed one out of three users interacting with the mobile app 20-40 days (or 2-4 days weekly) and one



(a) 1st intervention (b) 2nd intervention period (c) 3rd intervention period

Figure 3. Days during which PT pilot users (top) and GR pilot users (bottom) interacted with the mobile apps.

out of five doing so only rarely (less than once per week).

On the contrary, in the third intervention period, we clearly evidence fewer "devoted" users than in the second intervention period, namely users who interact with the app daily. A Kolmogorov-Smirnov (K-S) test for the app usage in the two periods does not reject the hypothesis that the two datasets are from the same continuous distribution ($p = 0.49$).

In the PT pilot, the engagement of users with the app and its evolution over time have different characteristics (Fig. 3(a)). More than 3 out of 4 app users use the app only occasionally during the first intervention period. The user engagement with the app gets better in subsequent periods. During the second intervention period is overall higher and more uniformly spread in the interval 1-5 days per week. Moreover, we identify a 10% of users that interact daily with the app during the third intervention (for the period we have data available). Finally, the DE pilot's participants interact on average one hour per day with the app/portal (to be precise, 1.079 hours) and they are active during one third of the days.

On average, in the three pilots, the pilot participants can be grouped into three groups of low (app access once per week), medium (app access 2-5 times per week) and high (daily access) engagement. For the GR pilot, the partition of participants into the three groups is (51, 33, 16), for the PT pilot it is (45, 26, 24), and for the DE pilot (75, 20, 5).

To get a closer look into the characteristics of the users' interaction with the mobile apps (duration, frequency) in the GR and PT pilots, we define sessions as intervals of continuous user activity, namely sequences of logged events that are not separated in time by more than a seconds. We have experimented with threshold a values of 3, 5, 10, 15, 20, 40 mins and we have found that the session characteristics are practically the same when $5 < \alpha < 40$ mins. For these values, we log 1-7 sessions per user on a weekly basis lasting less than one minute.

3.2 User exposure to nudges

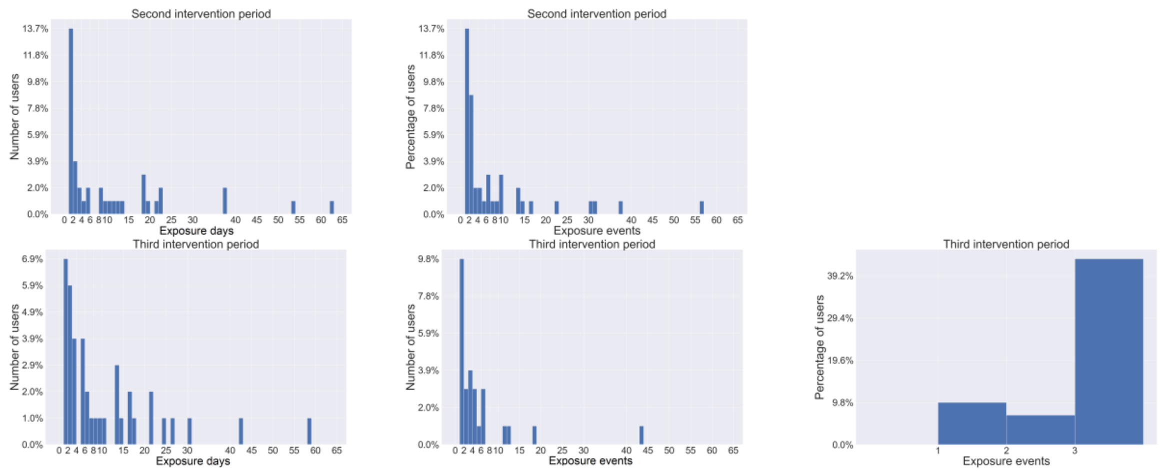
Besides the overall interaction of users with the digital tools, we want to know how much of this interaction relates to their nudging features. Notably, the nudges in the DE and GR pilots are accumulated over time*, i.e.*, the k^{th} nudge, k=2,3, is superimposed to nudges {1,..,k-1} in the k^{th} intervention period, whereas the PT pilot participants are exposed to a single nudge.

The measure of exposure varies with the nudge type. Hence, for feedback and awareness-type or nudges (1^{st} nudge in all pilots, 2^{nd} and 3^{rd} nudge in the PT pilot) that can be accessed anytime, we count the distinct days that the feedback screens/pages were accessed. For the event-based just-in-time prompts (nudge 2 in the GR pilot), we measure distinct events, whereas for push notifications (nudge 3 in the GR and nudge 2 in the PT pilots) we count the notification events that were viewed (consumed) by the participants.

In the GR pilot (Fig. 4), 65% of participants are exposed to (one of the) nudges for 1-11 days per 8-week intervention cycle, corresponding to less than twice per week. When looking into each nudge separately, approximately 40% of the pilot participants are exposed to 1-11 events for nudge 2 and 3 events for nudge 3, during the 2^{nd} and 3^{rd} intervention periods, respectively. It is important to mention that nudge 3 notifications/ messages were mostly sent 3 specific days during the third intervention period. In terms of nudge popularity, 75% of nudging events in the 2^{nd} period and 85% in the third period are related to nudge 1. For nudge 3, users rarely interact with the received notifications, as 92% were ignored. On the other hand, users were more responsive to in-app received messages, as they opened 63% of them.

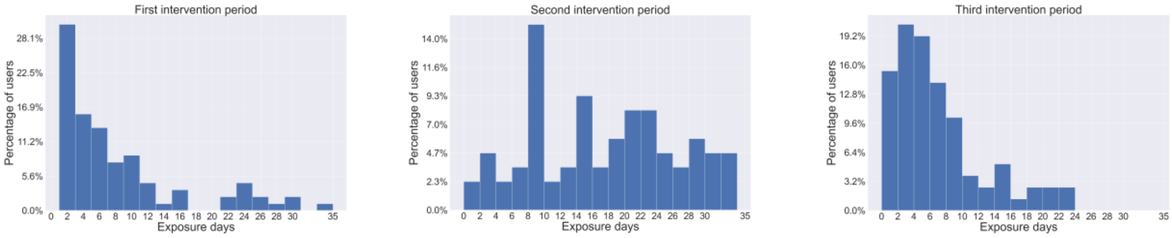
For the PT pilot, increased exposure is recorded for nudge 2 (Fig. 5), most of the users being exposed to it from 6 up to 26 days. However, the exposure level decreases during the other two intervention periods to 1-11 days, but with 39% of the users exposed 2-6 days during nudge 3.

Compared to the GR pilot, in the PT pilot the exposure to nudges is slightly increased, as users are directly exposed to nudges through the main screen. Furthermore, 60% of the users are exposed at least once per week to a nudge during the second and third intervention periods. Similarly to the GR pilot, notifications did not enjoy much attraction since participants interacted with 9% of the 894 received notifications during the 3^{rd} intervention.



(a) nudge 1 (b) nudge 2 (c) nudge 3

Figure 4. Days/occasions during which GR pilot participants were exposed to the app’s nudging features



(a) nudge 1 (b) nudge 2 (c) nudge 3

Figure 5. Days during which PT pilot participants were exposed to the app's nudging features

In the DE pilot, out of the 111 participants, 98 interacted with the relevant nudge pages at least once during nudge 2 and 88 did so during nudge 3. Notably, the nudge exposure was increased for nudge 3, more than 83% of users being active per group. For nudge 3 and the first half of nudge 2, most of the participants interacted with the nudge pages for 1 to 10 days (in particular, 59.6% for the first half of nudge 2, 86.7% for the first and 75.9% for the second half of nudge 3). This low number of activity days for the vast majority during nudge 3 is expected, since these nudges do not require much interaction.

For the second half of nudge 2, 42.9 % of the participants were active for 11 to 30 days, which is expected the specific intervention lasted longer. A minority of participants was also active beyond 30 days, which corresponds almost to every nudge day (e.g., 14.6% for the first half of nudge 2, 4.4% for the first half of nudge 3, 5.6% for the second half of nudge 3).

3.3 Correlation between application use and user exposure to nudges

To detect potential correlations between application use and nudge exposure, we cluster users based on the number of days they were exposed to nudges (*nudging exposure*) and the number of days they used the app (*engagement*). The typical clustering structure consists of four clusters and is shown in Fig. 6 for the GR pilot participants.

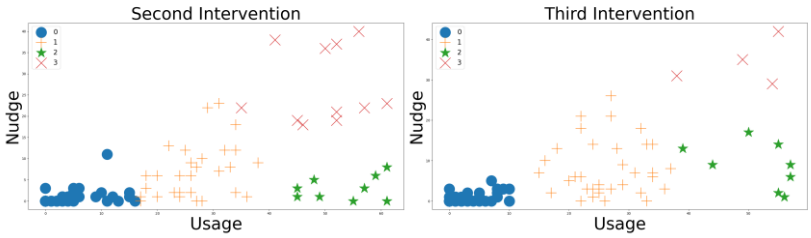


Figure 6. Clustering structuring emerging from grouping the GR pilot application according to their engagement with the DOMX app (in days) and their overall exposure to its nudging features (in days).

In all pilots, the highest portion of users is placed in the (low engagement, low nudging exposure) group (cluster 0 in Fig. 6). The highest percentage of participants in this group is recorded for the DE pilot, as users spend a maximum of 10 hours per week interacting with the Web portal. On the other side, the DE pilot seems to also feature the fewest users in the (high engagement, high nudging exposure) group (cluster 3 in Fig. 6). The other two clusters lying in between the two extreme ones, combine low exposure to nudging with either medium (cluster 1) or high (cluster 2) engagement with the app.

3.4 Correlation between application data and survey data

As a final task, we compared our findings about the engagement of pilot participants with the two mobile apps against their statements in the surveys that succeeded the nudging interventions. One set of statements related to their overall view of the application (Fig. 7), rating it from 1 (most positive) to 9 (most negative). The clear majority of pilot participants rate both apps positively and their ratings improve substantially from the 1st to the 2nd intervention, pointing to learning and training effects. With regard to individual aspects, they appreciate its time-saving features (mean rating=2.3), its comprehensibility (mean rating=2), and user-friendliness (mean rating=1.9).

In another survey question, the participants were requested to report the number of times they use the application per week. Interestingly, the provided answers by most participants stand at odds with their actual application usage. Hence, 58% of participants overestimate the frequency of app usage and another 35% underestimate it, with only 21.5% of the GR pilot and 39% of the PT pilot participants having a precise perception of how frequently they use the app. This is evidence that one needs to be cautious when analysing survey statements rather than a symptom of the social desirability bias.

Finally, a third set of questions in the three post-intervention surveys assessed the motivation and intention of users to reduce energy consumption on a scale from 1 (least likely) to 5 (most likely). The analysis of those ratings showed that, on average, there are no major rating deviations between intervention periods, but also among the pilots (Table 3). Specifically, the users' motivation to save energy is neutral (average rating is 3) and the intention of saving energy is a bit higher than the one of motivation (average score is 4). We computed the average intention and motivation scores within each of the clusters we derived in section 3.2.3 to figure out whether the two constructs differentiate from cluster to cluster, thus correlating with the usage app and/or exposure to their nudging features. The results per cluster are similar with the reported score of the total population, for both motivation and intention, as shown in Table 2.

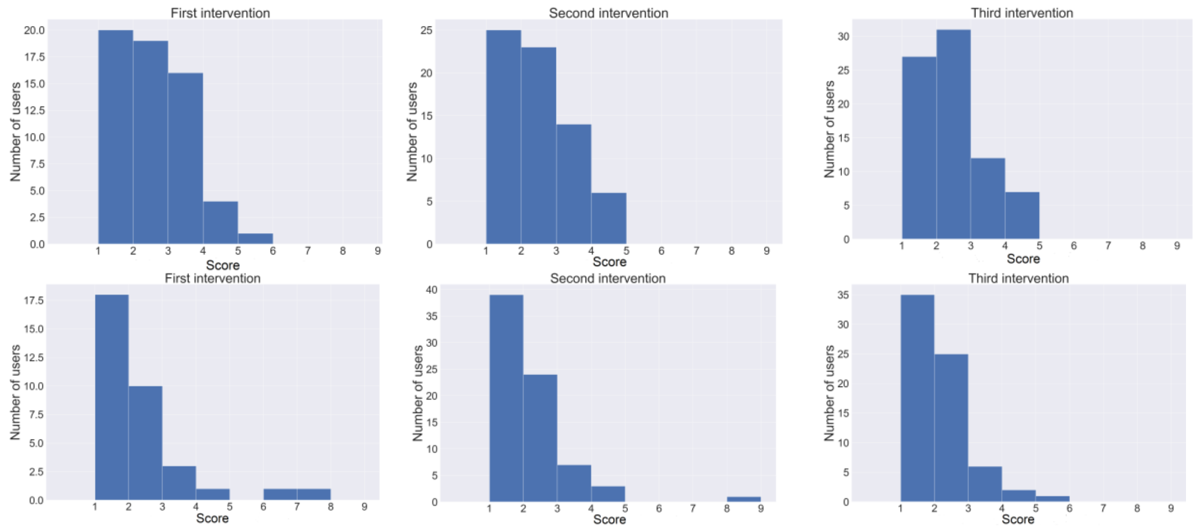


Figure 7. Distribution of app ratings at 1-9 scale according to the responses of PT (top) and GR (bottom) pilot participants in the three post-intervention surveys

Table 2. Energy saving intention and motivation ratings for the clusters of GR and PT pilot participants in section 3.3

	Total population	First Cluster	Second Cluster	Third Cluster	Fourth Cluster
GR pilot Second Intervention/ Third Intervention					
Intention	3.83/3.74	3.72/3.45	3.89/4.03	3.82/4	4/3.47
Motivation	2.79/2.99	2.9/3.05	2.89/3.03	2.62/2.84	2.48/2.45
PT pilot First Intervention/ Second Intervention/ Third Intervention					
Intention	3.77/3.96/3.97	3.75/3.87/3.93	3.8/4.1/4.1	3.8/3.99/3.91	-/4/3.91
Motivation	2.77/2.43/2.26	2.79/2.59/2.32	2.73/2.34/2.19	2.77/2.31/2.24	-/2.45/2.23

4. CONCLUSIONS

The analysis of data from three pilots provided useful insights for mobile app engagement and usage in the context of digital nudging. Over 76% of the participants interacted at least once with the digital tools that deliver the nudges, with an average frequency of 11 days per intervention period. Furthermore, the average user's nudge exposure was twice per week, but more than half of the users are not exposed to nudges on a weekly basis. The exposure rate of participants depended heavily on the type of nudge (e.g., feedback, push-notification etc.). Feedback nudges were most popular as a means of informing users about energy consumption (approximately 70% of nudging events). On the other hand, push-notifications nudges had low responsiveness, since users interacted only with 8.5% of them, on average. For the GR and PT pilots, in particular, their participants can be grouped into four clusters depending on the level of engagement with the app and their exposure to the nudging features of the app. Disappointingly, more than half the pilot participants belong to the cluster combining low engagement with low exposure to nudging.

Small details matter when trying to deliver nudges via digital means. Making the nudge integral part of the app homepage, as in the PT pilot, facilitates its delivery to the app user, when compared to embedding it in a separate page the user needs to explicitly access, as the case was with the GR pilot. Yet, the correlation of the nudging frequency with the (self-stated) intentions to save energy is rather weak. As future work, our goal is to understand the impact of nudging exposure on the actual users' energy consumption behaviour and explore whether it is possible to predict it based on their nudging exposure through statistical learning models.

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