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Research article

Nudging and citizen science: The effectiveness of feedback in energy-demand management

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ABSTRACT

Nudging is a framework for directing individuals toward better behavior, both for personal and societal benefits, through heuristics that drive the decision-making process but without preventing any available choice. Considering the Grand Challenges that our society faces today, nudging represents an effective framework to tackle some of these pressing issues. In this work, we assessed the effectiveness of informational nudges in the form of detailed, customized feedback, within an energy-demand-management project. The project aligns energy production and demand, thereby reducing greenhouse gases and pollutant emissions to mitigate climate change. We also offered evidence that this kind of feedback is efficacious in involving individuals as citizen scientists, who volunteer their efforts toward the success of the environmentally-related aim of the project. The results of this research – based on surveys, electroencephalography measurements and online participation measures – indicate that feedback can be an effective tool to steer participants' behavior under the libertarian paternalistic view of nudging, increase their motivation to contribute to citizen science, and improve their awareness about environmentally-related issues. In so doing, we provide evidence that nudging and citizen science can be jointly adopted toward the mitigation of pressing environmental issues.

1. Introduction

> "A good system of choice architecture [nudging] helps people to improve their ability to map and hence to select options that will make them better off" (Thaler and Sunstein, 2008, page 94).

As proposed by the 2017 Nobel Prize winner for research on behavioral economics, nudging constitutes a framework for influencing individuals toward better decision making for themselves and for society as a whole, with heuristics that drive the behavior process without forbidding any choice. Human behavior is based on two different cognitive systems: one very fast and grounded in automatic intuition, and the other slow and reason-based (Stanovich and West, 2003). The use of nudging can allow its recipients to automatize every-day decisions that otherwise may require slower reasoning to be made correctly, thereby avoiding some systematic decision-making errors.

Since the book of Thaler and Sunstein was published in 2008 (Thaler and Sunstein, 2008), nudging has drawn considerable attention. The goal of nudging is to influence people, while they face daily choices, toward better behavior through a proper design of choice architectures (Benartzi et al., 2017; Grieco et al., 2018; Thaler and Sunstein, 2008). In light of the recent focus given to Grand Challenges worldwide (Foray et al., 2012), nudges can be an effective means to face such issues. The Grand Challenges set open-ended global objectives, such as secure, clean and efficient energy production (Foray et al., 2012). To achieve these aims, different technological innovations, organizational solutions and policymaking decisions can be explored at a global level, involving organizations, institutions and the general public (Fagerberg, 2018; Kuhlmann and Rip, 2018).

One of the most pressing objectives that calls for the involvement of the general public is the reduction of greenhouse gases and pollutant emissions, as also outlined by the recent report from the United Nations (United Nations, 2018). This objective is crucial for the wellbeing of the entire society, because these emissions play a critical role in global temperature rise, which must be kept well below a 2-degree-Celsius increase over pre-industrial levels, and, more in general, in climate

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change that we are presently experiencing (Henderson et al., 2016; Yu et al., 2019). The 2018 report highlighted that notwithstanding the Paris Convention on climate change in 2015 (United Nations, 2015), greenhouse gases emissions rose in 2017, after three years of stagnation. New approaches should be explored to reach these environmental goals that are on policy agendas worldwide (Costa and Kahn, 2013; Kuhlmann and Rip, 2018). In this study, we demonstrate that the framework of nudging hold promise in reducing greenhouse gases and pollutant emissions related to household-appliance usage by acting on individuals' habits. Influencing individuals toward a better usage of appliances might favor better alignment between energy production and consumption, i.e., energy-demand management, which, in turn, could help reduce emissions and costs of electricity usage.

There are different heuristics that can be leveraged to nudge individuals. Thaler and Sunstein report that "One way to do this is to make the information about various options more comprehensible" (2008, page 94). In this regard, we provided participants with detailed feedback about information that are *publicly available* but *not easily understandable*. To make information more comprehensible to individuals, we reframed it in a ready-for-actual-use form. Following the paternalistic view of nudging, we left the individuals the freedom to choose their behavior without exaggerating the consequences of their actions (Thaler and Sunstein, 2008). More specifically, we presented individuals with an informational nudge, in the form of detailed, customized feedback about the impact of their choices on economic and environmental sustainability. While previous studies utilized other forms of nudging based on incentives or social comparison to diminish the overall households' energy consumption (Allcott and Kessler, 2019; Allcott and Rogers, 2012; Costa and Kahn, 2013; Delmas et al., 2013; Jessoe and Rapson, 2014; List and Price, 2016; Myers and Souza, 2020; Sudarshan, 2017), we considered the use of detailed, customized feedback for an improved energy-demand management.

Reducing the economic and environmental impact of electricity production calls for the collection of useful data about household-appliance usage. Here, we obtain information about personal usage of electricity from the individuals themselves. The quantitative understanding of appliance usage from data collected by citizens could inform the design of effective policies for energy-production approaches towards better energy-demand management. The voluntary involvement of individuals in research projects regarding environmental issues falls under the larger scope of citizen science. Recent advancements in information technology have facilitated the involvement of crowds from outside organizational boundaries for the generation and dissemination of new knowledge (Cappa et al., 2019; Franzoni and Sauermann, 2014; Majchrzak and Malhotra, 2013; Sauermann and Franzoni, 2015). When dispersed individuals are recruited in exchange of a bounty to work on new ideas for solving problems and for innovating, we speak of "crowdsourcing" (Afuah and Tucci, 2013; Lee and Seo, 2016; Natalicchio et al., 2017); but, we refer to citizen science when they are voluntarily involved in the collection or analysis of data that leads to knowledge creation (Auerbach et al., 2019; Cappa et al., 2016b; Young et al., 2019).

Citizen science constitutes an increasingly popular framework for involving volunteers from the general public, who are known as "citizen scientists," in authentic scientific projects (Dickinson et al., 2012; Groulx et al., 2017; Riesch et al., 2013; Science Europe, 2018). Citizen science is extensively leveraged in environmentally-related research projects, where no particular level of scientific background by the participants is usually needed. Citizens can contribute to scientific projects in various ways, from data collection to data analysis (Bonney et al., 2016; Haklay, 2013; Wiggins and Crowston, 2015); these efforts could also indirectly benefit research that addresses the Grand Challenges (Stilgoe et al., 2013; van Oost et al., 2016). In the present study, we focused on the involvement of citizen scientists as "sensors" (Haklay, 2013), whereby individuals provided data that could be later utilized by professional scientists for better planning of energy production and for targeting actions that could reduce households' energy consumption. The study of the motivation that underlies participation in citizen science has attracted significant scholarly attention in recent years (Cappa et al., 2018, 2016b; Franzoni and Sauermann, 2014; Laut et al., 2017; Nov et al., 2014; Palermo et al., 2017b; Schroer and Hertel, 2009). We add to this stream of literature through the analysis of the effects brought about by detailed customized feedback on citizen scientists' motivation to contribute.

Another merit of citizen science is to improve citizens' scientific literacy (Bonney et al., 2009; Science Europe, 2018; Turrini et al., 2018), which, in this work, relates to increasing their awareness about environmentally-related topics. Toward this aim, we also analyzed the positive impact that detailed, customized feedback – which makes publicly available information more easily comprehensible – has on citizens' motivation to contribute to data collection in research projects and on their scientific awareness. Identifying avenues to strengthen research project and improving scientific literacy are critical in the management of citizen science projects, since motivation drives both the initial decision to participate and the long-term involvement (Nov et al., 2014; Rotman et al., 2012) and literacy favors more responsible conducts (Groulx et al., 2017; Pisello et al., 2017).

Based on the above-mentioned groundings, we expected that feedback would play a central role in nudging and citizen science. Therefore, the research question we addressed was: can detailed, customized feedback provided to citizens be effective in nudging their behavior, in motivating them to contribute to citizen science and in increasing their awareness level about environmentally-related issues? To this end, we conducted randomized experiments in the context of an energy-demand-management project, entailing the reduction of electricity costs and of emissions related to households' electricity usage.

The findings of this work provide evidence of the benefits brought about by feedback in terms of nudging individuals, motivating them to contribute to citizen science projects and increasing their awareness levels. Detailed, customized feedback has been shown to constitute an effective informational nudge, under the paternalistic view of nudging. We grounded our reasoning in the Cognitive Evaluation Theory (Deci and Ryan, 1985; Gagné and Deci, 2005; Ryan and Deci, 2000a; Shi et al., 2017), which we propose as a theoretical basis for the informational-nudging heuristic. Given that collecting data about personal electricity consumption is crucial for the environmentally-related aim of the project, we also highlighted how feedback increase individuals' motivation to contribute to citizen science projects. In so doing, we sought to advance the literature on methodologies for increasing citizen scientists' motivation (Cappa et al., 2018, 2016b; Franzoni and Sauermann, 2014; Laut et al., 2017; Nov et al., 2014; Palermo et al., 2017b; Schroer and Hertel, 2009), by theorizing and empirically assessing the positive effect of detailed feedback. Our results further suggest that feedback can bolster participants' awareness of environmentally-related topics and objectives, which is another deliverable for policymakers and researchers. Therefore, we evidenced the feasibility of combining the two frameworks of nudging and citizen science bringing benefits to researchers, individuals and society as a whole. The combination of empirical measures to assess citizens' motivation (surveys, a web-based platform, and electroencephalography (EEG) measurements) constitutes another contribution of this work, toward a new synergistic standard for studying citizens' response.

The paper is organized as follows: in Section 2, we report the theoretical basis and the hypotheses of the study; in Section 3, we detail the methodology of the statistical analyses; and, in Section 4, we highlight the outcomes of the analyses. In Section 5, we discuss our results and comment on the contributions, limitations, and potential area of further inquiry of our research. Finally, in Section 6, we report the conclusions of our study.

2. Theoretical background and hypotheses

Nudges are aimed at inducing people to take what they would recognize as better decisions if they were experts in the field (Thaler and Sunstein, 2008). The assumption is that humans tend to make irrational, wrong choices in a systematic way (Lehner et al., 2016). Human beings are not perfect decision makers: they mainly rely on the so-called "System 1" thinking, which is fast and automatic, or on the slow and effortful reasoning underlying "System 2" thinking (Kahneman, 2003; Li and Chapman, 2013). Nudges leverage heuristics to simplify the decision-choice process by making the desired behavior more intuitive for individuals (Thaler and Sunstein, 2008). Following the paternalistic view of nudging, however, individuals are free to decide their preferred behavior without any imposing mechanism. In so doing, nudges follow a top-down approach where the flow of information is from organizations to individuals, but without employing the use of any enforcing mechanisms, such as punishments or overemphasizing the consequences of the choices. Thus, nudging leaves individuals with complete autonomy in their decision-making process (Thaler and Sunstein, 2008).

Different methods can be used for nudging individuals (Kahneman, 2012; Rivers et al., 2017; Sunstein, 2015a, 2015b, 2014), and successful applications of nudging were demonstrated in several contexts, such as promoting savings accounts, college enrollment, health insurance campaigns, and donations to programs in marine coastal management (Benartzi et al., 2017; Clark et al., 2014; Dai et al., 2017; Lehner et al., 2016; Nelson et al., 2019; Rogers et al., 2015; Thaler and Benartzi, 2004). As human behavior continues to be at the core of many complex environmental problems, nudging may also become critical to direct the general public toward meeting the Grand Challenges (Li et al., 2016; Schubert, 2017), i.e., pressing societal issues such as the reduction of electricity costs and emissions in the atmosphere. While previous studies leveraged social comparisons and incentives for nudging energy savings (Abrahamse et al., 2007; Agarwal et al., 2017; Allcott and Rogers, 2012; Benartzi et al., 2017), we employ detailed feedback based on publicly available information as a nudge for citizens' decisions in energy-demand management.

The context of this study is an ongoing energy-demand-management project, aimed at reducing greenhouse gases and pollutant emissions related to electricity usage, a goal that almost all nations have now endorsed (Abrahamse et al., 2007; Fagerberg, 2018; United Nations, 2018; 2015). Finding effective solutions to tackle costs and emissions related to energy consumption is of fundamental importance for our society (Agarwal et al., 2017), and it requires technological innovation, changes in governance structure, and interventions in citizens' ways of life (Fagerberg, 2018). In fact, households account for around 20% of the overall amount of emissions in the United States and in the European Union (Abrahamse et al., 2007; Eurostat, 2017), and electricity consumption in buildings is responsible for almost half of the world's electricity consumption (Berardi, 2016). Three different strategies can be implemented to decrease buildings' electricity-related costs and emissions: (i) a greater efficiency of energy plants, (ii) a lower energy-demand, and (iii) better coupling of energy production and use (Cappa et al., 2015; Corgnati et al., 2017). The last element, which is the focus of our study, is known as energy-demand management. It relates to the fact that demand peaks, which occur in the middle of workdays, force energy carriers to utilize inefficient plants that are effective for only a few hours a day, and they cause higher costs, greenhouse gases, and other pollutant emissions (Fagerberg, 2018). The possible deferral of electricity usage (e.g., dishwasher cycle) could allow reducing costs for households and diminishing global emissions (Zhou et al., 2016).

On a global scale, nudging individuals toward better behavior by deferring energy usage might be more feasible than decreasing their overall consumption. Therefore, feedback tailored to each individual may provide more comprehensible information useful to make better decisions, while leaving them the freedom of choice. In this work, we tackle the limited awareness of citizens that could lead them to dismiss relevant, publicly available information about the consequences of their decisions in appliances usage (Bazerman and Sezer, 2016), by providing them with detailed, customized feedback. Grounding our study in Cognitive Evaluation Theory (Deci and Ryan, 1985; Gagné and Deci, 2005; Ryan and Deci, 2000a; Shi et al., 2017), we argue that providing detailed and ready-for-actual-use information should facilitate individual cognitive evaluation of their possible behavioral opportunities and, consequently, it might improve their attitude toward following the suggested behavior. We thus made information that is publicly available more readily useable, highlighting aspects that are not usually taken into account in decision-making by individuals due to their complexity. The aim of the proposed informational nudge was to stimulate citizens to adopt more environmentally-friendly and sustainable behaviors in the context of energy-demand management. In particular, the setting of this study was the B.E. Smart project, which stands for "Building Energy Smart," as it deals with electrical-appliance usage in the context of residential energy-demand management, and its name can also be read – itself a nudge – as "Be Smart," a suggestion to individuals to adopt better behavior.

We offered two types of feedback to nudge individuals, one aimed toward personal benefit and the other toward societal benefit. The first type of feedback contained information regarding personal electricity cost savings that could be achieved by deferring appliance usage as suggested. The second instance of feedback concerned additional information related to emission savings that could be spurred by following the suggestion provided, thereby reducing pollution in the atmosphere. These two types of feedback were tested separately as they impinged on different benefits that can derive from energy-demand management, namely cost reductions as a personal benefit and pollutant-emissions reductions as a societal benefit. Based on the above considerations, the first hypothesis we tested was the following:

Hypothesis 1. *Feedback regarding personal or societal benefit, in energy-demand-management projects, nudges individuals toward suggested behavior.*

The environmental aim of facilitating energy-demand management is also related to the need of acquiring refined, personalized data about individuals' electricity usage. Knowledge about the preferred time for each type of appliance usage may aid in planning energy production and in identifying potential actions for reducing household-energy consumption (Aristeidou et al., 2017; Cappa et al., 2015; Killion et al., 2018). Therefore, the collection of data about citizens' energy usage may be extremely useful (Cotterill et al., 2009). Citizen science offers a potent framework to address this need, by actively involving citizens, i.e., "citizen scientists," to satisfy scientific needs as set forth by professional scientists (Dean et al., 2018). Citizen science connects professional scientists with members of the public for scientific purposes, with a particular emphasis on solving environmental issues (Rowbotham et al., 2019; Turrini et al., 2018). In citizen science, individuals collaborate with professional researchers without any particular preliminary knowledge required. Environmentally-related issues constitute a desirable context for citizen science, because it calls for extensive involvement of citizens without imposing any technical background requirement (Bonney et al., 2009; Crain et al., 2014; Dickinson et al., 2012). Citizen science projects can be useful for: (i) professional researchers, as massive datasets can be collected and used for scientific purposes; (ii) participants, since scientific literacy and appreciation of academic inquiry are enhanced; and (iii) society as a whole, as the research projects often share an environmental focus that might benefit the general public. To this end, the B.E. Smart project seeks to collect data from citizens about their habits regarding appliance usage to allow better planning of electricity production and usage.

Citizen science projects may follow a top-down logic, where scientists and academic institutions or non-profit organizations set the project target and citizens are involved solely in data collection; or they may use a bottom-up logic, where only the general traits are given by the professional scientists and the research question and the analysis arise from citizens' contributions (Newman et al., 2012). In the B.E. Smart project, the research question, protocol of data collection and data analysis follow a top-down approach to citizen science (Killion et al., 2018; Pocock et al., 2017), where citizens are involved as data "sensors" (Haklay, 2013; Wiggins and Crowston, 2015). The growth of citizen science is facilitated by recent advancements in information technologies that enable people to easily access and collaborate with scientists, thus overcoming geographical, social, cultural, and physical barriers (Brossard et al., 2005; Cappa et al., 2016b). However, contributions from citizen scientists are highly volatile, and several of these online communities compete for volunteers, highlighting the need to devise strategies for increasing citizen scientists' motivation to participate (Dahlander and Piezunka, 2014; Nov et al., 2014; Sauermann and Franzoni, 2015; Tinati et al., 2017; Wald et al., 2016). Through this targeted endeavor, we attempt to contribute to this field of research by examining the feasibility of increasing motivation to participate in citizen science projects through detailed, customized feedback. Citizen scientists and professional researchers are often two disjointed communities, and detailed information offered to citizen scientists is expected to constitute a novel experience that may benefit their motivation to contribute, while drawing the two communities into a higher degree of interaction.

Therefore, a second objective of this study was to test the use of detailed, customized feedback, based on the impact of their behavioral decisions and regarding the best time to use electrical appliances, as a way to bolster motivation to contribute to a citizen science project. We expected that providing citizens with information not commonly available to them would increase their engagement and enjoyment levels, which are the main constituents of citizen scientists' motivation (Aristeidou et al., 2017; Cappa et al., 2016b; Laut et al., 2017), and drive both the initial decision to participate and the continued contributions over time (Nov et al., 2014; Rotman et al., 2012).

Building again on Cognitive Evaluation Theory (Deci and Ryan, 1985; Gagné and Deci, 2005; Ryan and Deci, 2000a; Shi et al., 2017), granting participants detailed feedback about their potential role toward personal and societal benefits, i.e., cost savings and pollutant-emissions reductions respectively, should enhance their motivation to contribute. When citizens contribute as mere "sensors" of data, their cognitive engagement is minimal, but providing them with additional information through feedback may activate their cognitive process and further motivate them to participate (Haklay, 2013). Moreover, feedback might highlight to participants the importance of their continuing participation, thereby enhancing their motivation toward the achievement of the scientific and societal aims (Deci and Ryan, 2012, 2000).

We expected that both types of feedback, i.e., cost savings as a personal benefit and pollutant-emissions reductions as a societal benefit, should play a role. Previous research demonstrated that participants in other crowd-based projects, like crowdsourcing for idea collection (Cappa et al., 2019; Majchrzak and Malhotra, 2013) or crowdfunding for funds collection (Cappa et al., 2020; Mollick, 2014), can be interested in contributing due to the pleasure in favoring a common societal aim, i.e., intrinsic motivation, and/or in receiving a personal benefit, i.e., extrinsic motivation (Füller et al., 2011; Raddick et al., 2013). In citizen science, which is another crowd-based project typology, participants are mainly involved due to intrinsic motivation, i.e., the pleasure and accomplishment in helping addressing an environmental issue (Cappa et al., 2018; Franzoni and Sauermann, 2014; Sauermann and Franzoni, 2015). Tools that enhance extrinsic motivation, e.g., the use of a reward, may crowd-out contributors who had been intrinsically motivated to participate in voluntary activities such as citizen science (Fiorillo, 2011; Ryan and Deci, 2000b; Seidel and Langner, 2015; Titmuss, 1998). Feedback regarding pollutant-emissions reductions is clearly aligned with the voluntary basis of citizen science, whereby it highlights a societal benefit that can be achieved through participation in the project. On the other hand, feedback regarding personal cost-savings avoids the risk of leaning toward a monetary reward that can crowd-out participants. Such a feedback should be perceived as the reinforcement of an already publicly available information, which would be made more easily comprehensible and immediately useable. The two instances of feedback are apt to leverage the intrinsic pleasure of contributing to the citizen science projects in different ways. In fact, they provide two different detailed areas of information that typically are not given to participants, and, consequently, are tested separately, since the audience can be more affected by one or the other factor. Therefore, the second hypothesis we tested is:

Hypothesis 2. *Feedback regarding personal or societal benefits, in energy-demand-management projects, increases citizen scientists' motivation to contribute.*

In addition to nudging citizens and increasing their motivation to contribute to citizen science projects, the feedback provided may also improve their awareness of environmentally-related issues, which is paramount for individuals to better understand the overall scientific problem and to act accordingly (Pisello et al., 2017). Increased citizens' awareness allows for sensitization about the environmentally-related topic and, consequently, more cautious behavior (Church et al., 2018; Jordan et al., 2011). Public literacy is another deliverable of citizen science projects, and of great interest for policymakers (Bonney et al., 2009; Sauermann and Franzoni, 2015; Science Europe, 2018; Turrini et al., 2018). In fact, citizen science deals with delivering scientific outcomes, in terms of data collection and potential analysis, and it also aims at bringing about educational outcomes, in terms of improving participants' understanding of science and of environmentally-related issues (Bonney et al., 2009). As previous studies found mixed results with respect to increases in awareness levels after participating in citizen science projects (Bonney et al., 2016, 2009; Druschke and Seltzer, 2012), there is a notable gap in documenting awareness improvements in environmentally-related citizen science projects (Groulx et al., 2017). We expect that the detailed customized feedback tested in this study, which is not typically provided in regular citizen science projects, could foster citizen scientists' interest toward the projects' aims, improving their awareness about environmentally-related topics. This evidence constituted the grounding for the third hypothesis of this study, that is:

Hypothesis 3. *Feedback regarding personal or societal benefit in energy-demand-management projects increases citizens' awareness of environmentally-related issues.*

Besides alternatively offering the two types of feedback to participants, we also exposed citizens to both of them simultaneously. Though sharing similarities in their underlying theoretical groundings, the two instances of feedback – based on personal and societal benefits respectively – emphasize different types of information and can be used as complements in increasing citizens' motivation to contribute. Thus, individuals may acquire information related to both costs and emissions connected to their energy usage, which leverage different aspects of participants' intrinsic motivation. The simultaneous presence of these two detailed types of feedback supports the view that both individual and societal benefits can be accomplished together (Bonaccorsi and Rossi, 2003; Krishnamurthy et al., 2014). Therefore, we expected that behavior, motivation, and awareness levels should all be influenced to a greater extent by leveraging both types of feedback simultaneously. From this assumption, the following fourth hypothesis was tested:

Hypothesis 4. *Feedback regarding both personal and societal benefits magnifies the positive impact on individuals' nudged behavior toward a suggested decision, on their motivation to contribute to the citizen science project, and on their awareness about environmentally-related issues.*

The four previously mentioned hypotheses are summarized in the model shown in Fig. 1.

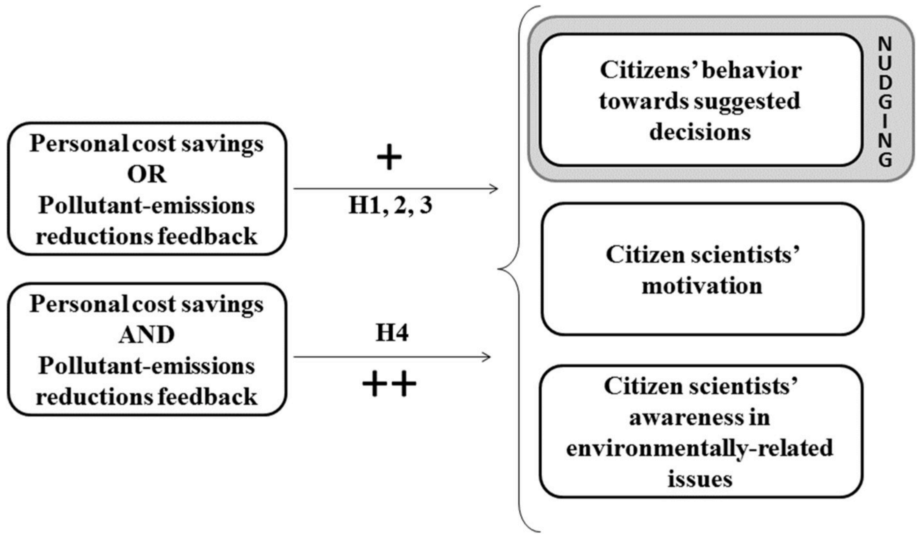

Fig. 1. Hypotheses on the effect of feedback on citizens' behavior toward suggested decisions, and citizen scientists' motivation and awareness in energy-demand management.

3. Research method

The present research was carried out by considering an active citizen science project, B.E. Smart, which is the test bed of our hypotheses. The project is based on an in-house developed, web-based platform for inducing better behavior and for collecting citizens' data in the context of residential energy-demand management. The web-based platform was created to connect citizen scientists with the project, collecting their energy-usage preferences and offering them detailed, customized feedback, in terms of the consequences of their behavior for personal electricity costs and CO_2 emissions, and suggesting the most convenient hours to use domestic appliances.

In this study, we considered CO_2 as a proxy for greenhouse gas and pollutant emissions, being it an environmentally harmful result of the electricity production and usage. This classification of CO_2 is in line with recent policymakers' orientation (see for example Environmental Protection Agency in USA (Barnes, 2014; Harder, 2014; Kintisch, 2011; United States Environmental Protection Agency, 2018, 2015) and with recent research articles and registered patents (Casas-Ledón et al., 2017; Deng et al., 2016; Jin et al., 2017). By employing the above-mentioned web-based platform, citizens were provided with different types of feedback. We conducted randomized experiments, which are effective in the estimation of causal effects (Imai et al., 2010), with four different conditions.

To Group 0, the reference condition of our study, no detailed, customized feedback was offered; rather, the group received only the suggestion to defer their appliance usage for better energy-demand management. This control condition emulates the typical environment in which individuals conduct their daily behavioral choices, whereby they might know that it could be better to run the appliances in the evening but have no ready-for-actual-use information about the consequent impact of their choice. Therefore, in this condition, participants were provided with a suggestion on when it is better, for themselves and for society at large, to defer the appliance usage but without having the detailed, customized feedback about the specific effect of their behavior, which was instead provided to the other treatment conditions. Participants assigned to Group 1a and 1b received feedback regarding the impact of their behavioral change, in terms of cost savings as a personal benefit or pollutant-emissions reductions as a societal benefit, respectively. Finally, individuals in Group 2 received both types of feedback, i.e., cost savings and pollutant-emissions reductions, together.

In line with other experimental studies about nudging (Lehmann et al., 2016), we collected more than 30 participants per condition for a total of 123 participants to conduct paired *t*-tests. The sample size is sufficient for extrapolating statistically significant conclusions from our results, based on the power analysis that was conducted. Participants were recruited from a pool of students in an Italian University during the academic year 2016–2017, and they contributed on a voluntary basis, as authentic citizen scientists. The use of students permits having a homogenous pool for the experiment, allowing for the isolation of other confounding variables that could have affected the results of the study. As a confirmation of the suitability of such a sample of participants, the involvement of students in experimental settings is increasing in scientific research (Cappa et al., 2018; Druckman and Kam, 2011; Vanasupa et al., 2011). Individuals were randomly assigned to one of the four conditions (i.e., no feedback for Group 0, € savings for Group 1a, CO_2 savings for Group 1b, and €+CO_2 savings for Group 2), and they participated anonymously.

The experimental set-up was composed of a portable stand; a laptop computer; an in-house developed, web-based platform; a paper-based 7-point Likert scale surveys; EEG helmet device to measure participants' enjoyment and engagement levels from brainwaves. The synergistic use of the above-mentioned several measures to investigate our hypotheses was aimed at reducing common-method bias (Podsakoff et al., 2003).

3.1. Web-based platform

The in-house developed, web-based platform of the B.E. Smart project provides clear, concise and easy-to-read web pages to participants, able to increase their awareness levels about energy consumption, production and management, as well as about emissions in the atmosphere. These contents can be found under the "Learn" tab on the website (Figure A reported in the Supplementary Material). Users can click on specific topics, e.g., "Global warming," to receive a brief explanation of each of the main issues related to the environmental aim of the project, i.e., mitigating climate change.

In addition, the platform permits the users to be directly involved in energy-demand-management procedures with respect to their appliance usage, by means of the tab "Manage your consumption" (Fig. 2). Here, users can insert: (i) the hours when they want to employ a given home appliance, (ii) their location and (iii) the type of home appliance they are going to use and its energy class, or, alternatively, the power [kW] that the appliance requires.

The calculation of energy costs and CO_2 savings is conducted automatically by the web-based platform with an in-house developed algorithm. Users receive real-time customized feedback about their

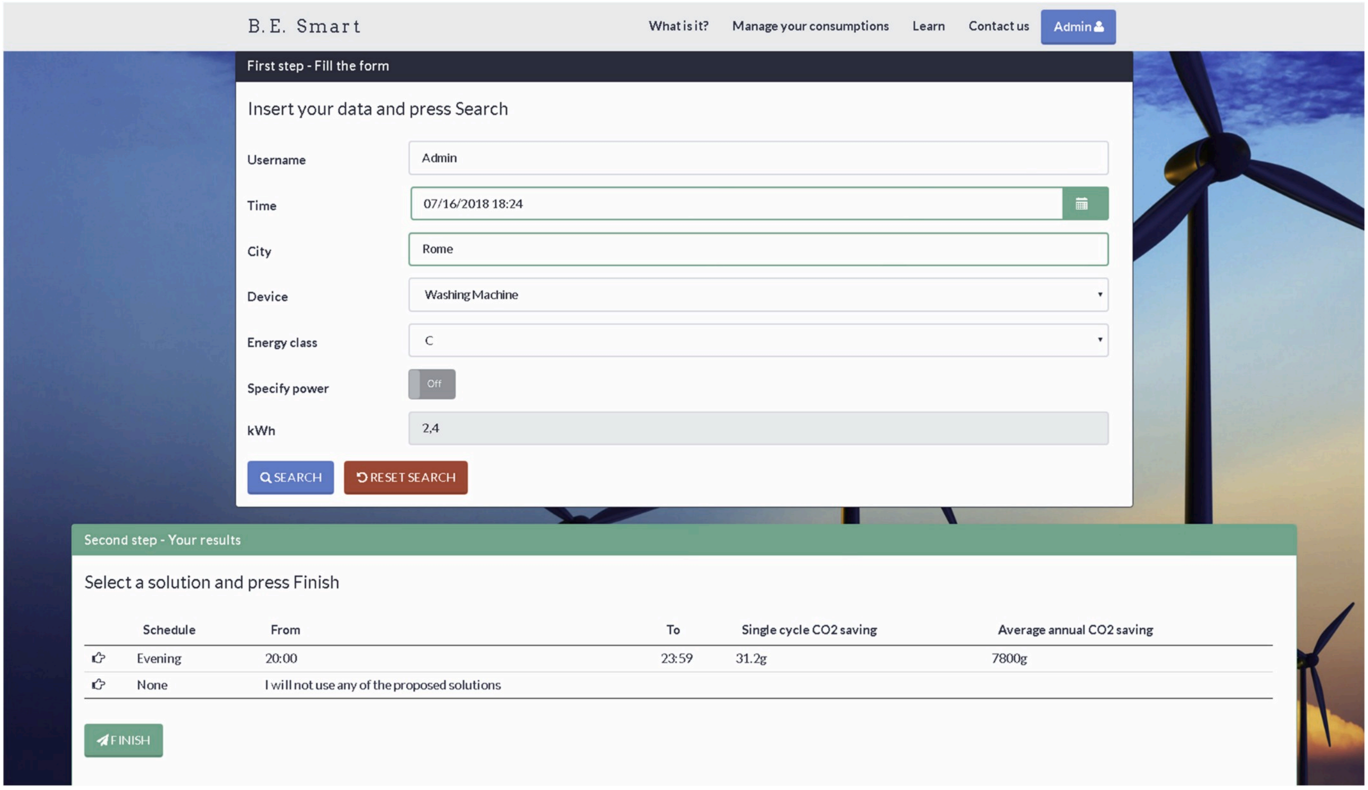

Fig. 2. B.E. Smart web-based platform feedback results after the algorithm computations for Group 1b. (Group 1a and 2 offer different feedback, i.e. € savings and €+CO_2 savings respectively, while Group 0 offer only the suggested time to which defer the appliance usage).

appliances usage, based on the information they have inserted. For this study, the algorithm was based on the Italian electricity market, characterized by a two-fee structure, i.e., different costs during peak and non-peak electricity-usage hours. Based on these fee-structures, we calculated the €/kWh and estimated the CO_2/kWh savings that could be achieved by shifting energy-demand from peak to non-peak hours. The price for domestic users during non-peak hours was on average 0.01 €/kWh lower than during peak hours, i.e., Monday–Friday from 9 a.m. to 7 p.m. (The Italian Regulatory Authority for Energy Networks and the Environment, 2016). Similarly, we estimated the amount of CO_2 that could be saved by shifting the electricity demand to non-peak hours to be equal to 13 g CO_2/kWh (The Italian Regulatory Authority for Energy Networks and the Environment, 2011). The average amount of kWh per each usage of the appliances was also estimated from the efficiency label ("Energy Class") used in the European Union, along with the typical amount of usage cycles during an entire year. These computations allowed us to estimate the € and CO_2 savings per cycle and per year for each of the appliances.

After allowing the user to insert information about the appliance (i.e., type, location, efficiency level, and the time when it is planned to be used), the website uses a proprietary algorithm to propose the closest time for deferring the usage to reduce costs and/or emissions savings, or eventually without any feedback in the case of control condition (Fig. 2). The user is free to opt for deferring the appliance usage, thereby accepting the suggestion, reported as first option on the website following the nudging strategy to push towards better default options (Richler, 2020), which intends to nudge the user toward better behavior, or to continue with the initial plan, reported below the option to defer, and thus ignore the feedback provided. The website allows the researchers to keep track of the anonymous volunteers' interactions with the web-based platform by recording the users' decisions about deferring or non-deferring the appliance usage and recording the number of the platform's web pages that the user visited.

3.2. Data collection protocol

Individuals voluntarily approached the stand of the citizen science project that housed the experimental set-up in an empty room of the University. After receiving a brief explanation of the B.E. Smart project's aims and characteristics from a researcher present in the room, they freely decided to participate, as is customary in common citizen science projects (Aristeidou et al., 2017). Then, participants were randomly assigned to one of the four group conditions, i.e., Group 0, 1a, 1b, and 2, and they were unaware that other conditions existed. They were requested to fill-in an initial survey containing questions related to their propensity to contribute to energy savings and to citizen science projects, and to their awareness of environmental and energy issues. After the completion of the initial survey, participants were required to wear the EEG helmet device to measure their enjoyment and engagement levels. Then, they started interacting with the website, freely choosing whether or not to click on each tab. Upon completing the "Manage your consumption" form on the website at least once, which constitutes the data collection part for the scientific aim of the project, they could opt to terminate the interaction whenever they wanted. The participants of this experiment on average spent 10 min on the web-based platform, in line with previous studies analyzing citizen scientist participation (Cappa et al., 2018).

On the webmaster page, the website permits researchers to keep track of which feedback the participant visualizes (i.e., € savings, CO_2 savings, both of them, or neither of them), which webpages they visited, how many times they run the algorithm, and whether they intend to follow the suggested behavior in using the appliances.

To enhance the saliency of the interaction and standardize the treatment, all the experiments were conducted during the peak hours of electricity demand in Italy, thus from 12 p.m. to 4 p.m. After the interaction with the web-based platform, a second survey was provided to participants to again score their awareness and motivation to contribute to the citizen science project. We collected participants' data before, during and after the experience on the B.E. Smart web-based platform, and elaborated different measures, as described in the next subsection.

3.3. Measures

The effectiveness of nudging citizens was assessed through the amount of appliance-usage postponements, i.e., the number of behavioral changes contained in participants' responses (Measure A), as indicated by their intention to follow the suggestions provided in the feedback on the web-based platform. This number is an integer count collected automatically by the web-based platform and associated with each anonymous participant. Although this factor represents a measure of intended behavior, it has been shown in literature that behavioral intention is also an effective proxy of effective behavior (Nov et al., 2014).

Individuals' motivation to contribute to the citizen science project, i.e., enjoyment and engagement levels – factors that are accepted as key drivers of individuals' motivation (Aristeidou et al., 2017; Cappa et al., 2018, 2016b; Garcia Martinez, 2015) – were assessed through surveys administered before and after the experiments (Measures B1and B2), which allowed to collect discrete integer values from 1 to 7 about their enjoyment and engagement. The 7-point Likert scale surveys are reported in detail in Tables A and B in the Supplementary Material. Moreover, participants' motivation was also assessed by means of EEG measurements (Measure B3 for enjoyment and Measure B4 for engagement), which provide measured values rather than self-declared measures such as surveys. In fact, the EEG device was used to complement results of the surveys, which might be skewed due to participants' social-desirability bias (Moorman and Podsakoff, 1992), in order to avoid the common method bias (Podsakoff et al., 2003). The Emotiv Epoc portable EEG device ("Emotiv," 2017) used in this study was able to record brain activity through electrodes and to translate it into motivation measures (Duvinage et al., 2013; Schroer and Hertel, 2009). Through a proprietary algorithm, the EEG helmet provides instantaneous enjoyment and engagement continuous values, each ranging from 0 to 1 at a sampling rate of 128 Hz (Mihajlovic et al., 2014; Palermo et al., 2017a). From these measurements collected throughout the experiment, we computed the average values for each participant. In addition, we measured the number of direct contributions on the web-based platform of each individual during the experiment (Measure B5), i.e., the number of appliance-information inserted into the software. This number is a further measure of motivation, representing a proxy focused on long-term oriented motivation, which is crucial toward the sustained participation of individuals (Sauermann and Franzoni, 2015).

Table 1
Experimental design: groups and measures.

	Group 0	Group 1a	Group 1b	Group 2
Number of observations	30	31	31	31
Feedback	No feedback	Personal benefit (€ savings)	Societal benefit (CO_2 savings)	Personal + Societal benefits (€+CO_2 savings)
Measure A: Behavioral change	Number of suggestions provided by the website that were accepted			
Measure B: Motivation	Enjoyment and engagement (self-reported from survey, measured from EEG, and counted with the number of direct contributions on the web-based platform)			
Measure C: Awareness	Number of web pages that were read (from the website) and awareness increase from the surveys (one collected before and one after the interaction with the web-based platform)			

With respect to awareness of environmentally-related topics in the citizen science project, two measures were collected. First, we counted the number of web pages opened by participants (Measure C1), which contains information about electricity production, emissions in the atmosphere, and global-warming issues. This number, collected automatically by the web-based platform, is a proxy of the awareness increase achieved by accessing information on these specific topics. Second, the increase in awareness brought about by participating in this citizen science project was also assessed by comparing the results of the two surveys, evidenced as an effective method for the specific aim mentioned (Bonney et al., 2009), i.e., the one completed before the experiment and the one after the interaction with the website, with particular reference to questions related to participants' awareness of environmentally-related activities (Measure C2). As for the previous measures collected through surveys, we collected responses ranging from 1 to 7, reported in greater detail in the Supplementary Material.

The above-introduced measures are summarized in Table 1, and the relative descriptive statistics are reported in Table 2.

3.4. Statistical analyses

The statistical analyses were conducted with SPSS software (release 17). To assess the positive impact that the feedback has on citizens' behavioral changes, motivation to contribute and awareness, paired *t*-tests were conducted between the different feedback groups and the

Table 2
Descriptive statistics: mean values for each measure, standard deviations are in parentheses.

	Group 0	Group 1a	Group 1b	Group 2
Number of observations	30	31	31	31
Feedback	No feedback	€ savings	CO_2 savings	€+CO_2 savings
Measure A: Behavioral change	1.66	2.37	2.22	2.61
Number of suggestions accepted	(0.71)	(1.34)	(0.80)	(0.84)
Measure B1: Motivation	9.16	10.67	11.16	12.35
Enjoyment survey	(1.01)	(1.51)	(1.29)	(1.33)
Measure B2: Motivation	8.80	10.29	10.93	11.35
Engagement survey	(1.15)	(1.50)	(1.31)	(1.62)
Measure B3: Motivation	0.27	0.42	0.51	0.67
Enjoyment EEG	(0.16)	(0.17)	(0.21)	(0.21)
Measure B4: Motivation	0.55	0.58	0.60	0.60
Engagement EEG	(0.07)	(0.04)	(0.08)	(0.07)
Measure B5: Number of direct contributions	1.67	2.23	2.34	2.61
	(0.71)	(0.80)	(1.34)	(0.84)
Measure C1: Awareness	2.03	3.24	4.06	4
Number of web pages read	(1.37)	(1.29)	(1.65)	(1.18)
Measure C2: Awareness	0.96	2.76	4.58	3.54
Increase in survey responses	(1.88)	(4.12)	(4.01)	(4.66)

reference group (Hypotheses 1, 2 and 3). Moreover, the effects brought about by the simultaneous presence of two types of feedback were also tested with respect to reference and single feedback conditions (Hypothesis 4).

4. Results

Both the instances of feedback – provided separately – were able to nudge citizens in shifting their appliance usage toward better energy-demand management, thereby attaining lower individual costs and emissions in the atmosphere ($p < 0.001$). These claims offer compelling evidence in favor of Hypothesis 1.

In addition, the outcomes of the statistical analyses offer evidence on how motivation, i.e., enjoyment and engagement levels, increases when feedback is provided. Both the types of feedback provided to citizen scientists, i.e., personal cost saving and emissions reductions, led to a significant increase in their motivation to contribute to the citizen science project ($p < 0.001$). These results are consistent when looking at surveys' declared values, EEG measured values, and number of direct contributions during the experiment, thereby supporting Hypothesis 2.

Each of the instances of feedback was also successful in improving the awareness of participants with respect to the environmental issues of the project. This result is evidenced by the significant increases in survey marks regarding the awareness about the environmental issues considered and by the number of visited web pages on the web-based platform ($p < 0.05$ and $p < 0.001$, respectively). Both these improvements offer support for Hypothesis 3.

The results of the above-mentioned *t*-tests between treatment groups with one instance of feedback, i.e., Group 1a and 1b, and the reference condition, i.e., Group 0, are reported in Table 3.

We also tested the effectiveness of the contemporaneous provision of the two types of feedback, with respect to the reference condition (Group 0), and with respect to both of the conditions in which feedback was individually provided (Group 1a and Group 1b). The simultaneous presentation of the two types of feedback offers a statistically significant improvement with respect to the reference condition. However, the positive effect is significantly greater only in some of the tested metrics with respect to the conditions with just one type of feedback. Therefore, we conclude that Hypothesis 4 is partially supported by our experiments. The above-mentioned results are reported in Table 4.

Table 3
Results of *t*-test between Group 0, and Group 1a and Group 1b for each measure. The average difference and significance level are reported (* stands for $p < 0.10$; ** for $p < 0.05$; and *** for $p < 0.01$).

	€ savings with respect to No-feedback (Group 1a – Group 0)	CO2 savings with respect to No-feedback (Group 1b – Group 0)
Measure A: Behavior change Number of suggestions accepted	0.71***	0.55**
Measure B1: Motivation Enjoyment survey	1.50***	2.00***
Measure B2: Motivation Engagement survey	1.53***	2.20***
Measure B3: Motivation Enjoyment EEG	0.16***	0.25***
Measure B4: Motivation Engagement EEG	0.06***	0.04**
Measure B5: Number of direct contributions	0.56**	0.67**
Measure C1: Awareness Number of web pages read	1.06**	2.00***
Measure C2: Awareness Increase in survey responses	1.80**	3.61***

Table 4
Results of *t*-test between Group 2 and the other groups (Group 0, 1a and 1b). The average difference and significance level are also reported (* stands for $p < 0.10$; ** for $p < 0.05$; *** and for $p < 0.01$).

	CO_2 + € savings with respect to No feedback (Group 2 – Group 0)	CO_2 + € savings with respect to € savings (Group 2 – Group 1a)	CO_2 + € savings with respect to CO_2 savings (Group 2 – Group 1b)
Measure A: Behavior change Number of suggestions accepted	0.94***	0.26	0.38*
Measure B1: Motivation Enjoyment survey	3.22***	1.67***	1.19***
Measure B2: Motivation Engagement survey	2.56***	1.06**	0.41
Measure B3: Motivation Enjoyment EEG	0.41***	0.25***	0.16***
Measure B4: Motivation Engagement EEG	0.05**	0.013	0.009
Measure B5: Number of direct contributions	0.94***	0.38*	0.27
Measure C1: Awareness Number of web pages read	1.90***	0.83**	0.09
Measure C2: Awareness Increase in survey responses	2.58***	0.78	1.03

5. Discussion

Our study, grounded in the Cognitive Evaluation Theory, highlights the effectiveness of nudges in the context of environmentally-related behavior, where potential benefits pertain to both individuals and society at large. We studied the effectiveness of detailed, customized feedback as informational nudge, i.e., making information more comprehensible to the public (Thaler and Sunstein, 2008) in order to influence individuals' behavior for better energy-demand management. The feedback used to nudge the behavior of households with respect to their appliances usage was designed upon information that is publicly available, but that is not commonly taken into consideration in decision making by individuals because it is not easily comprehensible. By quantifying the positive effects brought about by different combinations of feedback – i.e., related either to cost savings as a personal benefit, to emissions reductions as a societal benefit, or both of them – we provide evidence of the effectiveness of nudging interventions in the context of energy-demand management.

The informational nudge was offered to participants without using manipulative tactics, such as exaggerating the consequences of their actions, which could force them toward a presumably best choice via incentives or fees, or by presenting overly-pessimistic statements (Momsen and Stoerk, 2014; Rivers et al., 2017). Following the paternalistic view of nudging, participants maintained their decision-making autonomy, while receiving detailed and customized information, (Delmas et al., 2013; Thaler and Sunstein, 2008). Therefore, the trust relationship between scientists and citizens, and more broadly policymakers and citizens, will likely be preserved, while offering the possibility of modulating human behavior. These informational nudges do not impinge on the amount of energy used by households, but are intended to optimize energy usage with respect to peak demand and energy production. Hence, they are expected to be more easily accepted by citizens with respect to other policies focusing on decreasing the overall energy-demand (Abrahamse et al., 2007; Corgnati et al., 2017; Delmas et al., 2013; Fischer, 2008) or on increasing the acceptability of energy-related decisions (Steinhorst and Matthies, 2016). Considering that the web-based platform developed and used for this project can reach a wide audience worldwide, this study further evidences how information technology can enhance nudging implementations (Castellacci and Tveito, 2018).

In addition, our study explored how to motivate people to contribute to citizen science projects for scientific purposes. Indeed, people can be involved in science as active and informed subjects leading to significant technical progress by collecting data for professional scientists. It is increasingly clear that "research consortia" involving citizens and professional researchers can foster responsible research aimed at addressing society's Grand Challenges (Stilgoe et al., 2013; van Oost et al., 2016). Since citizens might be involved worldwide in energy-demand-management projects, it is tenable to provide professional scientists with data about household energy consumption for better energy-demand-management planning. Collecting large amounts of data is crucial for environmental issues, aimed toward gaining useful insights for policymaking and remedial strategies (Zhou et al., 2016). Therefore, motivating citizens to contribute to citizen science is critical to collect great amounts of data for scientific purposes. Based on Cognitive Evaluation Theory, the provision of feedback is able to effectively motivate citizens to participate in the project by leveraging their cognitive engagement. Improvement in participants' motivation was documented through surveys (self-declared values of enjoyment and engagement levels), EEG measurements (measured values of enjoyment and engagement levels), and number of direct contributions (count of contributions on the web-based platform). The use of three types of measures reduces common method biases (Podsakoff et al., 2003) and strengthens the validity of the outcomes of this study.

The detailed, customized feedback offered to citizens was also effective in increasing their awareness levels on environmentally-related topics, which is critical for the success of citizen science projects and for policymaking in general. In fact, the increase of citizens' awareness on these topics may further aid better planning of electricity usage by increasing the sensitization of people toward this matter. While Druschke and Seltzer (2012) found that when contributing to citizen science, individuals do not achieve the educational goal required, through this study we show that providing citizen scientists feedback that contains ready-for-actual-use information may increase their awareness in the environmentally-related aim of the project. While scholars have largely relied on surveys to assess the awareness level (Bonney et al., 2016, 2009; Druschke and Seltzer, 2012), our results are validated by the use of surveys and of the effective number of webpages opened. Given the breadth of citizen science projects and the large basis of prospective volunteers, this claim bears considerable relevance.

Finally, offering both types of feedback about personal and societal benefits – i.e., those related to personal cost as well as to emissions savings – was found to be beneficial with respect to the control condition, but it was not conducive to increases in all the measures analyzed with respect to single-feedback conditions. In particular, a significantly stronger effect on citizens' behavioral changes, motivation and awareness levels was not consistently revealed in all the metrics with respect to the single-feedback condition. This result might be due to a ceiling effect, whereby a single instance of feedback is sufficient to nudge participants, keep them motivated to contribute, and increase their awareness.

5.1. Contributions

With this study, we contribute a better scientific understanding of nudging and citizen science in several ways. First, we provide a theoretical grounding of the nudging framework based on information heuristics. We based our study on Cognitive Evaluation Theory (Deci and Ryan, 1985; Gagné and Deci, 2005; Ryan and Deci, 2000a; Shi et al., 2017) to support the effectiveness of feedback under the paternalistic view of nudging (Thaler and Sunstein, 2008). This result is relevant to achieve a better comprehension of how informational nudges can support their broader implementation. By providing empirical evidence of the effects of two types of feedback – i.e., one based on energy cost savings as a personal benefit and another based on emissions reduction as a societal benefit – within an energy-demand-management project, we enrich the toolbox of effective nudges and widen the context where nudging contributes positive effects (Thaler and Sunstein, 2008). The nudges used in this study are based on detailed feedback, rather than additional incentives or comparisons with neighbors to drive people behavior as done in previous studies (Allcott and Kessler, 2019; Allcott and Rogers, 2012; Delmas et al., 2013; Myers and Majluf, 1984; Sudarshan, 2017). The nudging aim is not for reducing the overall households' energy demand (Abrahamse et al., 2007; Agarwal et al., 2017; Allcott and Kessler, 2019; Allcott and Rogers, 2012; Delmas et al., 2013; Myers and Souza, 2020; Sudarshan, 2017), for promoting an energy audit (Gillingham and Tsvetanov, 2018) or for favoring the adoption of energy from renewables (Momsen and Stoerk, 2014), but rather to encourage a better alignment of energy production and consumption. For these reasons, the typology and aim of the nudges used in this study is likely to more easily implementable worldwide. In so doing, we respond to the call for evaluating additional types of nudges that can shape the behavior of citizens toward environmental aims (Benartzi et al., 2017; Costa and Kahn, 2013).

A second contribution of this study is the evidence of the effectiveness above-mentioned types of detailed and customized feedback as mechanisms to increase individuals' motivation to contribute to citizen science projects. Considering that several citizen science projects fail over time due to limited volunteer participation, the study of motivation underlying participation in online platforms has attracted significant scholarly attention in recent years (Franzoni and Sauermann, 2014; Nov et al., 2014; Palermo et al., 2017b; Schroer and Hertel, 2009). Recent studies focused on face-to-face interactions with researchers, rewards for contributing, and comparison with virtual competitors to positively influence volunteers' motivation to participate in citizen science (Cappa et al., 2018, 2016b; Laut et al., 2017). Through this targeted endeavor, we contribute to this field of research by documenting the feasibility of increasing motivation to participate in citizen science through detailed, customized feedback offered to participants. Through this research, we highlight how Cognitive Evaluation Theory could be the appropriate theoretical scheme to explain the increase of citizens' motivation through the use of feedback. Providing participants with detailed understanding about their potential role toward cost savings and pollutant-emissions reductions makes it possible to enhance their cognitive involvement and therefore their motivation to contribute. Given the scope of the B.E. Smart project, in which citizen scientists serve as data "sensors," their cognitive engagement is minimal. Hence, providing them with additional information could activate their cognitive process and further motivate them to participate (Haklay, 2013). Moreover, the detailed, customized feedback will involve citizens as active and informed contributors to scientific projects, letting them decide what and how much data to share with the scientists, thereby fostering their motivation toward the achievement of the scientific and societal aims at stake (Deci and Ryan, 2012, 2000). We also empirically quantified the benefits of detailed, customized feedback to motivate citizen scientists to participate, adding to the stream of literature about increasing volunteers' motivation in citizen science (Cappa et al., 2016b; Laut et al., 2017; Oreg and Nov, 2008; Palermo et al., 2017b; Raddick et al., 2013).

In addition to nudging citizens' behavior and increasing their motivation to participate in data collection, we also report that the feedback provided may improve their awareness of environmentally-related issues, which is paramount for them to better understand the overall scientific problem and to act accordingly (Pisello et al., 2017). In fact, general public literacy is another deliverable of citizen science projects, and it is of great interest for policymakers (Bonney et al., 2009; Science Europe, 2018; Turrini et al., 2018). Considering the empirical context of this study, almost 40% of the global population remains unaware of greenhouse gases and pollutant-emissions issues, while research examining climate change as a social-mobilization problem recognizes the need to foster individual awareness (Groulx et al., 2017). Therefore, our research contributes to such a need of increasing the general public-awareness about environmentally-related issues, by supporting the effectiveness of detailed, customized feedback toward this aim.

In a broader view of our results, a further contribution of this research is to document the effectiveness of the simultaneous application of nudging and citizen science, which can function as complementary frameworks to address the Grand Challenges. In fact, both nudging and citizen science are here construed within a top-down relationship between academic researchers and citizens, and they can be synergistically implemented. We measured and presented the environmentally-related benefits brought about by the use of feedback in terms of nudged behavior, of increased motivation to contribute to citizen science projects, and of improved citizen awareness levels. By so doing, we propose that integrating these two frameworks can be effective in benefiting individuals and society as a whole.

An additional contribution of this study is the combination of EEG measurements and surveys that may offer a new standard by which to conduct empirical research on motivation in citizen science and related fields of study. While previous studies on design interventions to enhance participants' motivation have largely relied on surveys (Cappa et al., 2016b), we integrated surveys with EEG measurements to avoid common method and social desirability biases (Moorman and Podsakoff, 1992; Podsakoff et al., 2003). The combination of self-declared and measured values constitutes a promising approach to reinforce the validity of empirical findings. Because EEG devices will become more portable and more readily available on the market throughout the coming years, demonstrating their consistency with respect to traditional survey instruments is another merit of this work.

5.2. Policy implications

Technological innovations are not the only factors that can play a role in tackling the Grand Challenges; good policy models should also be developed to this end (Fagerberg, 2018). Through recent advancements in information technologies, we highlighted that nudging can be an effective tool to involve individuals toward the achievement of these societal aims by directing people toward better behavior. As part of this trend, the United States started a new, national research team devoted to this topic, called the "Social and Behavioral Science Team" (Obama, 2015), aimed at inducing people to make better decisions. Within this realm, research consortia that foster citizen science can play a critical role, as demonstrated by the integration of citizen science elements in the Transparency and Participation Act in Germany(Kuhlmann and Rip, 2018). The importance of citizen science is also supported by the forum organized by the US White House in 2015, where it was proposed that "members of the public can advance scientific knowledge and benefit society" (Science Europe, 2018). Our study prompts policymakers to favor the simultaneous implementation of nudging and citizen science for addressing the Grand Challenges.

The premise of including individuals in research activities dates back several decades with customer co-creation and lead-user practices (Herstatt and Von Hippel, 1992; von Hippel, 1986, 1976). In those contexts, the benefits were mainly private: for companies – which were able to deliver better innovations, and for customers – who could obtain better products and, albeit seldom, be rewarded. With the improvement of information technologies, the last decade has seen several new open-source communities, where individuals, rather than selected lead users, could offer their time in exchange for different kinds of monetary and non-monetary rewards (Bonaccorsi and Rossi, 2003; Fitzgerald, 2006; Roberts et al., 2006; von Krogh et al., 2012). This combination of collective gains and private benefits has fostered the diffusion of private-collective innovation models (von Hippel and von Krogh, 2006; von Hippel and von Krogh, 2003). By offering empirical support to the benefits of feedback in nudging and citizen science, we seek to lay the foundations for a private-collective research and sustainability model, which might be a policymaking focus over the coming years. In this model, individuals who might not meet any specific knowledge requirements could be involved for personal private gain in terms of reduced costs and increased literacy. Simultaneously, they can collect a massive dataset and embrace a better behavior for the public interest, in terms of reduced pollutant emissions. Thus, through the use of detailed, customized feedback, we may simultaneously enhance all three pillars of sustainability (Cappa et al., 2016a): environmental sustainability, by reducing pollutant emissions; social sustainability, by improving the general public awareness level; and economic sustainability, by potentially allowing cost saving for families.

6. Conclusions

With this study, we contribute some advancements of scientific knowledge about nudging and citizen science frameworks, through a theoretical grounding for their joint implementation and the quantification of their positive effects toward addressing the Grand Challenges. More specifically, in the context of an energy-demand management project, we provide evidence of the effectiveness of detailed, customized feedback in nudging citizens' behavior, in increasing their motivation to contribute to citizen science projects and in improving their awareness levels about environmentally-related issues. In so doing, we highlight the feasibility of the simultaneous application of these two frameworks towards the above-mentioned aims. Overall, the outcomes of this research advance the academic understanding of nudging and citizen science, and we provide professional researchers and policymakers with insight on how to better involve citizens – using detailed, customized feedback – toward a more sustainable society.

Our study is not free of limitations, which also pave the way for several future developments. While we measured the intention to behave in certain ways – following previous studies that evidenced how intention to behave is a good proxy of effective behavior (Nov et al., 2014) – future studies should explore how individuals effectively behave at home in real life conditions. Along the same lines, another interesting research effort might be a longitudinal study on the positive effects brought about by the feedback tested in this study to determine the durability of nudged behavior. We analyzed the effects of different types of feedback on nudged behavior, motivation to contribute to citizen science, and awareness levels of citizen scientists – all separately and simultaneously. Future research should explore the eventual mediation effects of these aspects (Imai et al., 2010). Likewise, another promising future research direction might be the extension of our findings in other environmentally-related projects, especially considering the numerous pressing Grand Challenges we face (Foray et al., 2012).

The outcomes of this study apply to the involvement of citizens as "sensors" for citizen science projects, i.e., individuals active in data collection. Future research should analyze how the feedback is also effective in other types of citizen science where, for example, individuals are active in data analysis. Moreover, as this research analyzed the positive effects brought about by feedback on citizen scientists' motivation, which the literature has indicated as a driver of intention of participation that can vary over time (Sauermann and Franzoni, 2015), future research may analyze the time evolution of motivation. Furthermore, while in this study we used students as the pool of participants for our experiments, to isolate the results from other confounding effects (Cappa et al., 2018; Druckman and Kam, 2011; Vanasupa et al., 2011), future studies should extend the findings of this study by testing them with a broader audience.

Given our focus on the effects of CO_2, future studies should also evaluate the effects of feedback based on other types of pollutants emitted in atmosphere to assess which may be the most effective. Another limitation that we acknowledge is that EEG measurements are generally time consuming, thereby challenging the feasibility of large-scale experiments. This limitation is partially evidenced by the number of participants involved in the experiments, although our findings seem rather robust with respect to the sample size. Thus, a future line of research might involve a larger sample to further validate the results. Another promising line of future research could entail the identification of the individuals' profiles that best fit each instance of the feedback provided, toward pinpointing targeted audiences for each of the feedback analyzed in this study.

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Declaration of competing interest

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

CRediT authorship contribution statement

Francesco Cappa: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Software, Visualization, Funding acquisition, Resources, Validation, Writing - original draft, Writing - review & editing, Project administration. **Federica Rosso:** Conceptualization, Methodology, Data curation, Visualization, Funding acquisition, Validation, Writing - original draft, Writing - review & editing. **Luca Giustiniano:** Conceptualization, Resources, Validation, Writing - review & editing, Supervision. **Maurizio Porfiri:** Conceptualization, Funding acquisition, Resources, Validation, Writing - review & editing, Supervision.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2020.110759.

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