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Not my responsibility: The framing of autonomous systems impacts sustainable choices

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ABSTRACT

Autonomous systems, such as autonomous lawnmowers, cars, and drones, are known to reduce users' sense of responsibility towards the tasks these systems carry out. However, no research to date has examined whether a reduced sense of responsibility may affect the sustainable choices users make when presented with such systems. We seek to investigate whether the framing of autonomous systems, meaning how the key characteristics of such systems are communicated to the user, can affect the user's sense of responsibility and in turn their sustainable product choices. Across three studies, we show that when autonomous systems are presented with an "autonomy frame", emphasizing their ability to handle tasks on the user's behalf, users feel a diminished sense of responsibility for the system's environmental impact. Crucially, we see that such a reduction in responsibility leads to a preference for less sustainable versions of the system (Studies 1 & 2). Instead, when employing an "energy efficiency frame", highlighting the system's ability to optimally manage energy consumption, users still feel a reduced sense of responsibility and yet they make more sustainable product choices, due to the activation of a prosocial focus (Study 3). This mechanism behind the energy efficiency frame's success offers a solution to counteract the negative effects observed when autonomous systems are given an autonomy frame.

1. Introduction

Autonomous systems are increasingly performing tasks previously carried out by humans (Agrawal et al., 2018; Hengstler et al., 2016; Parasuraman & Riley, 1997). From cars that brake automatically when sensing safety risks, to robotic mowers and vacuum cleaners that maintain lawns and floors, to lighting systems that adjust brightness without manual input, these systems function largely without human intervention. This automation offers users a range of potential benefits, including increased convenience and improved efficiency in resource management and consumption. However, research suggests that the way these benefits are communicated can significantly influence user perception and choices (Block & Keller, 1995; Levin et al., 1998). For example, a system framed primarily for convenience might lead to different user expectations than one framed as promoting sustainability. This topic has relevant implications because emphasizing one benefit rather than another can shape user decision-making and choices (Scheibenzuber et al., 2023; Seo & Park, 2019).

One of the main benefits of autonomous systems is their ability to perform tasks on the user's behalf (Kopalle et al., 2021). Moley Robotics, for instance, underscores that its robotic kitchen allows users "to save time and free up their day from routine cooking" (https://moley.com), iRobot states that its robotic vacuum cleaners help users clean their house "without moving a finger". Similarly, Google Home offers users "helpful devices for every room" and allows them to create "a smart home that helps with any household task". Similarly, other autonomous systems highlight that the user can "unlock hours and hours of free time" thanks to the system (https://www.husqvarna.com/ph/robotic-lawn-mowers/about/). Overall, the type of frame that emphasizes a product or system's ability to operate with little to no user intervention is one we label the autonomy frame, given its emphasis on functioning independently from the user. Broadly speaking, this frame can be applied to any product where the goal is to emphasize reduced user effort or involvement. When applied to autonomous systems, this frame can be seen as the "default", and its purpose is to communicate a form of convenience that the user receives from a system that operates largely independently.

Crucially, research shows that, as systems become more

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autonomous, users tend to feel less involved in their operation and less responsible for the outcomes (Jörling et al., 2019; Leung et al., 2018; Puntoni et al., 2020). For instance, in the context of self-driving cars, users may feel less accountable for driving behavior and even for accidents (Bonnefon et al., 2016; Gill, 2020). This suggests that employing an "autonomy frame," which emphasizes the system's independence from the user, may have downstream effects on the sustainable choices users make. Sustainable choices intended as the decision to act more or less sustainably, are intimately related to one's sense of responsibility. In fact, there's ample evidence showing that users tend to make sustainable choices when they feel responsible for the consequences of their actions (e.g. De Groot & Steg, 2009; Kaiser & Shimoda, 1999; Verma et al., 2019). For these reasons, examining the link between the sense of responsibility users feel when presented with autonomous systems, and the sustainable choices they make, is the focus of the current project.

Given that the autonomy frame may diminish users' sense of responsibility, it is worth considering alternative framing choices that could be applied to autonomous systems, and how these might impact decision-making. In particular, highlighting the energy efficiency benefits that users may derive from autonomous systems could offer a different perspective. Past studies have shown that message frames emphasizing energy efficiency or ecological benefits can elicit a prosocial focus (White et al., 2019), a mindset where individuals consider the impact of their actions on society and future generations. Unsurprisingly, a pro-social focus at the moment of decision-making increases the likelihood that users will make a sustainable choice, such as reducing their consumption (Farmer et al., 2017) or opting to recycle (Menegaki et al., 2009).

Could an "energy efficiency frame" that emphasizes the system's ability to optimally manage its energy consumption help mitigate any negative effects of the autonomy frame? There are numerous examples of autonomous systems being given an "energy efficiency frame": for example, Ecobee claims that its smart thermostats support the transition to cleaner energy and net-zero emissions in order to "create a more sustainable world" (https://www.ecobee.com/en-us/). Similarly, Amazon claims that their smart thermostats working with Alexa help users "save energy and reduce carbon emissions" (https://sustainability.aboutamazon.com/environment/products/devices). Husqvarna frames its autonomous lawn mowers as "emissions-free" systems "using minimal amount of energy" (https://www.husqvarna.com/ph/robotic-lawn-mowers/about/).

In sum, users tend to feel a reduced sense of responsibility for the tasks carried out by autonomous systems, given their lack of involvement (Murtagh et al., 2015; Puntoni et al., 2020), and these systems are often framed in ways that specifically emphasize this lack of involvement in tasks, i.e., an autonomy frame. However, no research to date has examined how this reduced sense of responsibility may impact the sustainable product choices the user makes when opting between more (or less) sustainable versions of the system itself. Furthermore, no research has compared different message frames that can be used to emphasize distinct benefits users derive from an autonomous system. We therefore ask the following research questions: Does an "autonomy frame" applied to autonomous systems induce a reduced sense of responsibility and, in turn, reduce the likelihood of making a sustainable product choice? If so, can an "energy efficiency frame" applied to autonomous systems help mitigate this effect?

With this paper, we contribute to the literature on communication strategies and autonomous technologies by showing that users, presented with an autonomous system, feel reduced responsibility for the system's environmental impact regardless of how the system is framed. Crucially, we show for the first time that the reduced sense of responsibility users feel towards autonomous systems (e.g. Murtagh et al., 2015; Puntoni et al., 2020) influences the choices they make, as they choose between more or less sustainable versions of the autonomous system. It appears from this research that communication strategies cannot reduce the lack of personal responsibility that users feel towards these systems. However, we demonstrate that framing the system as energy-efficient, rather than stressing its ability to function autonomously, leads users to opt for more sustainable versions of the system. This is because autonomous systems framed as energy-efficient activate a prosocial mindset that encourages more sustainable product choices.

The rest of the paper is structured as follows. We begin by providing an overview of the literature linking message framing and sustainable product choice. Next, we explore the connections between automation and personal responsibility. Our literature review then focuses on the framing of autonomous systems as "autonomy" by reviewing the literature that indirectly links this framing strategy to perceptions of personal responsibility and sustainable product choices. Similarly, we then review literature that links the framing of autonomous systems as "efficient" to users' notions of personal responsibility and sustainable behavior.

Following this, we present our conceptual model and hypotheses. To test these hypotheses, we conducted three studies, each of which is accompanied by a brief results section. Finally, we conclude with a general discussion that outlines the theoretical and practical implications of our findings.

2. Message framing and sustainable choice

Message framing, the strategic emphasis on specific attributes or outcomes within communication, has been shown to significantly influence user decision-making across diverse domains, including environmental campaigns, products, and services (Levin et al., 1998; Rothman & Salovey, 1997). By altering the presentation of information, message framing can guide individuals' attention toward specific benefits or risks, shaping their perceptions and choices. For instance, in sustainability contexts, Lagomarsino, Lemarié, and Puntiroli (2020) demonstrated that promotion-focused frames, which highlight environmental benefits that can be gained or achieved, are more effective in encouraging pro-environmental behaviors than prevention-focused frames, which emphasize avoiding harm to the planet. Lee, Aaker, and Gardner (2000) showed that message frames that emphasize individualistic versus collectivistic values can influence sustainable choices across different cultural contexts. Similarly, framing products as "eco-friendly" or "sustainable" can prompt decisions that prioritize environmental well-being over self-interest (Farmer et al., 2017; Mazar & Zhong, 2010).

In this paper, the sustainable choices we focus on relate to environmental sustainability, specifically in the context of energy efficiency and carbon emissions associated with the operation of autonomous systems. These decisions reflect users' preferences between more or less energy-intensive versions of a given system—such as opting for a powerful, fast device versus a slower but more eco-efficient alternative. As such, our work aligns closely with Goal 12 of the United Nations Sustainable Development Goals (SDGs), which emphasizes sustainable consumption and production patterns as essential for achieving global sustainable development, including reduced environmental impacts and increased resource efficiency. Importantly, the decisions consumers make about sustainability are often shaped by trade-offs between sustainability and other valued product attributes, and, when faced with such trade-offs, consumers' choices are influenced by how these competing attributes are framed and prioritized (Luchs and Kumar, 2017). This underscores the importance of understanding how the framing of autonomous systems impacts sustainable decision-making.

3. Automation and personal responsibility

Autonomous systems are designed to perform tasks independently, effectively taking over tasks that once required time and effort from users (de Bellis & Johar, 2020). Such systems can learn about their environment, self-diagnose their own service needs, adapt to users' preferences, communicate with other products or systems, and make relevant decisions (Porter & Heppelmann, 2014; Raff et al., 2020). Importantly, automation, by definition, involves delegating tasks traditionally performed by humans to autonomous or semi-autonomous systems (Hengstler et al., 2016). As a natural consequence, the user might feel less responsible for the way a task is carried out by an autonomous system and the outcome of such a task (Jörling et al., 2018, 2019). This "abdication" of responsibility involves individuals feeling less accountable for the consequences of their actions and shifting accountability to other agents, e.g., to other people (Bandura, 1990, 1999, 2007).

Unsurprisingly, a reduced sense of responsibility tends to emerge when autonomous systems operate with significant autonomy. For instance, users travelling in autonomous vehicles tend to feel less accountable for accidents that may occur, as the responsibility is perceived to lie with the system rather than the user (Ciardo et al., 2020; Gill, 2020). Furthermore, increased levels of technical autonomy are associated with greater perceptions of agency (Frischknecht, 2021). In fact, when autonomous system take agency over a task, this can create a "moral buffer" (Royakkers & van Est, 2015), where users tend to abdicate responsibility for the actions out by the system, but also for the consequences of the system's actions, e.g. environmental impact.

4. Automation's autonomy frame: personal responsibility and sustainable choice

A reduced sense of responsibility tends to promote undesirable behaviors and choices, such as excessive alcohol consumption (Hull, 1981), overeating (Hagen et al., 2017), over-spending while shopping (Baumeister, 2002), and unethical decision-making (Detert et al., 2008). This is likely because a reduced sense of responsibility leads to individuals feeling morally disengaged from the outcomes of their actions (Sharkey, 2011). In the context of sustainable choices, a reduced sense of responsibility is linked to less sustainable behaviors, including increased energy consumption and wasteful practices (Verma et al., 2019). Conversely, individuals who feel responsible for their own environmental impact are more likely to make sustainable choices (Kaiser & Shimoda, 1999), such as purchasing sustainable products (Nyborg et al., 2006). In the automation field, research suggests that users who interact with autonomous lighting or temperature controls feel a reduced sense of responsibility for the environmental impact of such systems, and, in turn, tend to display more wasteful behaviors (Murtagh et al., 2015). The key message here is that people tend to feel less responsible for the actions carried out by autonomous systems, and this reduced responsibility manifests itself in less sustainable choices.

Crucially, users also tend to attribute desirable outcomes to autonomous systems, such as greater precision (Hong et al., 2021). Furthermore, the degree of skill and agency attributed to autonomous systems increases when they are framed in terms of their technical capabilities, further reinforcing their perceived independence from the user (Frischknecht, 2001). These patterns suggest that how autonomous systems are presented can profoundly influence users' moral and practical engagement with them.

Building on these insights, it is important to examine how autonomous systems are presented to users, in order to understand why these systems may be leading to reduced feelings of responsibility, as well as unsustainable choices. Descriptions of autonomous technologies often highlight their capacity to "save time," "free users from effort," or "operate independently," framing these benefits as key selling points (Kopalle et al., 2021). In fact, a widespread way of describing automation, that we term the "autonomy frame", emphasizes the system's ability to function independently from the user. As autonomous systems are specifically designed to minimize human involvement by automating tasks (Hengstler et al., 2016), the "autonomy frame" can be seen as most standard framing of autonomous systems. While this type of frame aligns with the very essence of automation, such a message frame may unintentionally undermine the user's sense of responsibility for environmental consequences. For example, Nicholls and Strengers (2019) discuss how robotic vacuum cleaners, marketed for their convenience and ease of use, may encourage overuse, increasing energy consumption and undermining potential sustainability benefits. This highlights how automation framed around user convenience could potentially encourage behaviors that contrast with environmental goals.

Given these findings, it becomes critical to explore how the framing of autonomous systems affects user responsibility and sustainable decision-making. Without careful consideration, we risk normalizing patterns of low responsibility and careless overconsumption, as users are repeatedly presented with autonomous systems that may subtly encourage disengagement from their environmental consequences.

We hypothesize that an autonomy frame applied to an autonomous system will lead to abdication of responsibility for the system's environmental impact, which in turn should reduce sustainable choices. This hypothesis is grounded in the broader observation that reduced responsibility is often associated with behaviors that prioritize indulgence over sustainability (Baumeister, 2002; Hagen et al., 2017). By stressing autonomy, the autonomy frame is expected to reinforce the perception that the system, rather than the user, is responsible for task outcomes, resulting in less sustainable choices.

We therefore hypothesize that:

- **H1a.** Framing autonomous systems with an autonomy frame leads to users making less sustainable choices.
- **H1b.** Users' abdication of responsibility for the environmental impact of the system mediates the relationship between autonomous system with autonomy framing on the user's sustainable choice.

In the next section, we explore whether an alternative framing strategy based on emphasizing energy efficiency, can counteract the negative effects of autonomy framing and promote more sustainable choices.

5. Automation's energy efficiency frame: pro-social focus and sustainable choice

Autonomous systems are designed to perform tasks independently, often with minimal input from users (Hengstler et al., 2016). While the autonomy frame emphasizes these systems' autonomy and convenience, many autonomous systems are equally capable of managing their resources efficiently (Kopalle et al., 2021). This dual capacity means that users can be presented with the same system framed in two distinct ways: one highlighting its functionality and independence, and the other emphasizing its resource efficiency. The framing choice may influence decision-making, particularly in the context of sustainable choices.

Research on sustainability framing suggests that emphasizing eco-friendly attributes may shift users' focus toward prosocial values, potentially encouraging more sustainable decisions. For example, framing foods as sustainable has been shown to activate a prosocial focus, prompting individuals to prioritize collective wellbeing and consume less (Farmer et al., 2017). Similarly, exposure to eco-friendly systems has been linked to the activation of a "virtuous" mindset, which motivates subsequent moral behavior, such as charitable giving (Spielmann, 2021). These findings suggest that sustainability-related framing increases the salience of prosocial values like altruism and security (Bullard & Manchanda, 2013; Mazar & Zhong, 2010), encouraging users to consider the broader societal and environmental impact of their actions.

Applying these insights to autonomous systems, we posit that framing these technologies with an energy efficiency frame may activate a prosocial focus, encouraging users to make sustainable choices. For example, emphasizing the energy-saving features of a smart thermostat or the emissions-free operation of an autonomous lawnmower could lead users to prioritize eco-friendly versions of such systems. However, whether an energy efficiency frame can counteract the reduced sense of responsibility often associated with autonomous systems (Murtagh et al., 2015) remains an open question. By emphasizing eco-benefits such as energy conservation, the energy efficiency frame may encourage users to trade off performance-related features for sustainability benefits. While autonomous systems are increasingly framed as efficient in real-world marketing contexts (e.g., Ecobee's energy-saving thermostats), the behavioral effects of this framing on sustainable choice have yet to be systematically examined.

We propose that emphasizing eco-benefits through an energy efficiency frame may increase the likelihood of users choosing sustainable versions of autonomous systems. Specifically, this framing is expected to encourage users to prioritize sustainability, even when it involves trade-offs in performance (e.g., processing speed). Formally, we hypothesize:

- **H2a.** Framing autonomous systems with an energy efficiency frame (vs. autonomy frame) increases sustainable choice.
- **H2b.** Prosocial focus mediates the effect of the energy efficiency frame (vs. autonomy frame) on sustainable choice.

6. Empirical studies: overview

To examine how autonomy and energy efficiency framing affect sustainable product choices in autonomous systems, we conducted three studies that tested our hypotheses regarding the influence of message framing, responsibility abdication, and prosocial focus. Importantly, when it comes to sustainable product choices, users often need to trade off ecological benefits for other valued attributes (Luchs and Kumar, 2017), such as power or performance. Across all studies the sustainable product choices we examine are a trade-off of this kind, where a more sustainable choice of system implies that the system is likely to offer lower performance. Study 1 tested H1a and H2a, examining whether an autonomy frame (highlighting autonomy and convenience) versus an energy efficiency frame (emphasizing optimal resource management) influences users' sustainable product choices. The study compared autonomous systems to non-autonomous alternatives to establish baseline framing effects. Study 2 tested H1b and H2b by investigating the mediating roles of responsibility abdication and prosocial focus. Conducted in an incentive-compatible context, this study allowed participants to select their preferred system with the possibility of receiving it, providing evidence for the psychological mechanisms underlying the effects of framing. Study 3 validated the findings across a new context by employing an online behavioral task. This study tested all four hypotheses (H1a, H1b, H2a, H2b) to confirm the framing effects on sustainable product choices and to demonstrate the consistency of the mediating processes (responsibility abdication and prosocial focus). For an overview of the studies, the variables tested, and the type of trade-off that constituted the sustainable product choices we investigated see Fig. 1.

7. Study 1. differential effect of autonomy versus energy efficiency framing on sustainable product choice

Study 1 aimed to investigate the effect that frame exerts on users' sustainable product choices as well as the mechanisms underlying such an effect. In particular, the study tests whether autonomous systems lead to participants making less sustainable product choices compared to participants presented with a non-autonomous system. Importantly, we will be checking whether this effect depends on the frame that is used to communicate the system to the user: autonomy versus energy efficiency.

8. Methods

Three hundred and sixty-seven users ($M_{Age} = 39$, $SD = 12.93$; 49 % males) recruited from Mechanical Turk participated in a single-factor between-subjects online study with a control condition and two treatment conditions (autonomy vs. energy efficiency framing). An online questionnaire randomly assigned each participant to one of these three conditions. Participants were instructed to imagine that they were about to purchase a new fully electric car and received some information about the car's functionalities. The non-autonomous car scenario described

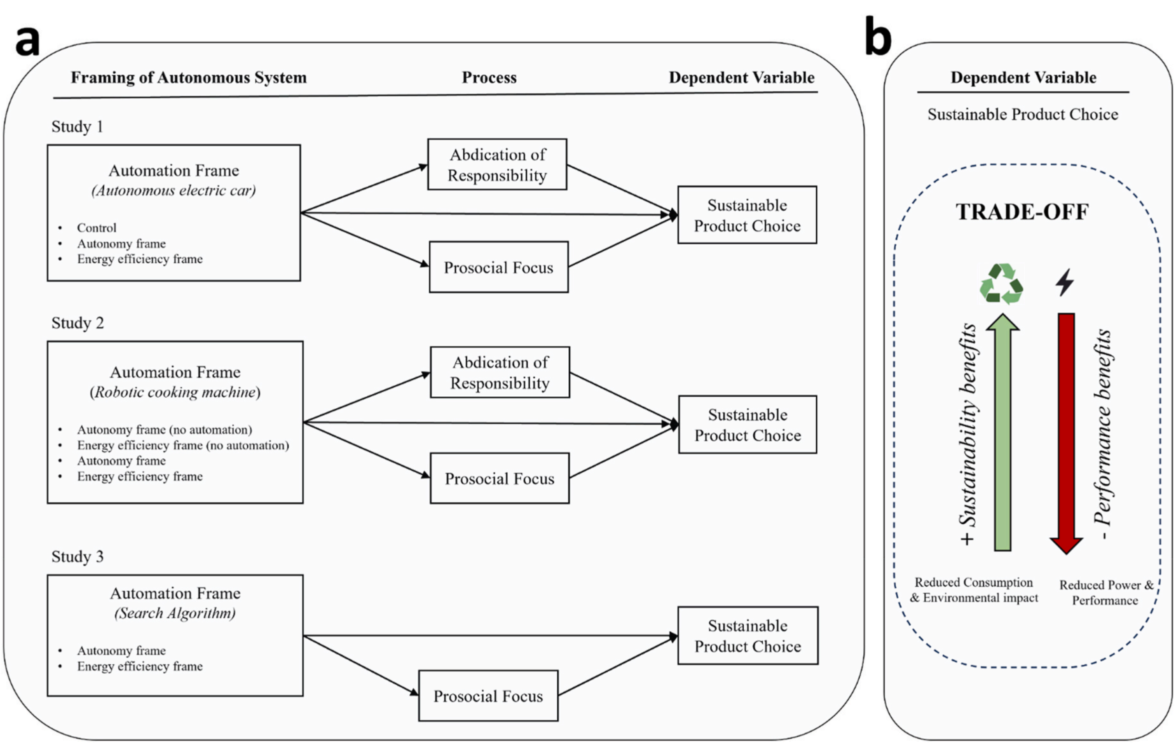

Fig. 1. Illustration of the Experimental Framework. (a) The sequence of studies, the different systems tested, the communication frames used and the relationships between the tested variables. (b) Breakdown of the sustainable product choices participants made when choosing their preferred version of an autonomous system. This choice required trading-off sustainability benefits for performance benefits.

these functionalities as "manual," without stressing their practical or sustainable benefits. The autonomous car scenarios described such functionalities as "automatic." Furthermore, participants assigned to the "autonomy" frame read that the carmaker primarily developed these features to increase the system's practicality, whereas participants assigned to the "energy efficiency" frame read that the carmaker primarily developed such features to reduce the car's energy consumption (see Appendix 1 - Table A1 for details).

8.1. Procedure

As many carmakers allow prospective buyers to fully customize their vehicle online before purchase, participants were required to first make choices relative to their preferred exterior and interior, helping them to fully immerse themselves into the experiment. Participants were then informed that they could choose among seven different versions of the car, which only differed in terms of power, ranging from 90 to 181 horsepower (HP), and thus in the amount of energy consumption. Since this trade-off between performance and energy efficiency was central to our measure of sustainable product choice, we used an ordinal variable (ranging from 1 to 7) to capture participants' graded preference for more or less energy-intensive systems. These seven possible versions of the car acted as our dependent variable for sustainable product choice. Participants were told that they had sufficient budget to buy any version of this system.

8.2. Measures

Participants indicated which HP version they preferred, and we reversed this measure to obtain an indicator of a sustainable system choice. Then, participants rated their abdication of responsibility for controlling the car's energy consumption ($\alpha = .90$) using a three-item scale adapted from Murtagh et al. (2015; see Appendix 4 for details) and their prosocial focus ($\alpha = .95$) using a three-item scale adapted from Farmer et al. (2017; see Appendix 4 for details). These two variables were constructed by averaging participants' scores on the different items. Finally, they completed two seven-point single-item scales (from 1 = "Not Very Much" to 7 = "Very Much"), which respectively assessed their perceptions of how autonomous and how sustainable the car was (as a manipulation check).

9. Results

We ran a series of initial analyses that confirmed the effectiveness of our manipulations (see Appendix 2). Participants assigned to the non-autonomous car scored significantly lower on abdication of responsibility than participants assigned to the *autonomy framed* autonomous car ($p = .003$, CI [-.98, −.20]) and the *energy efficiency frame* ($p = .007$, CI [-.91, −.15]), but this variable did not significantly differ between the two groups of participants assigned to the two framing conditions ($p = .775$, CI [-.34, .46]). Participants assigned to the *energy efficiency frame* rated their prosocial focus significantly higher than participants assigned to the non-autonomous car ($p < .001$, CI [.33, 1.18]) and the *autonomy framed* car ($p = .002$, CI [.27, 1.16]). Prosocial focus did not significantly change between these latter two groups ($p = .857$, CI [-.47, .39]).

A one-way between-subjects ANOVA indicated that sustainable product choice significantly varied across the study conditions (no automation, *autonomy frame*, and *energy efficiency frame*), $F(2, 366) = 13.70$, $p < .001$, partial $\eta^2 = .70$. In particular, the planned comparisons using Fisher's LSD method revealed that participants assigned to the *autonomy frame* made less sustainable product choices than participants assigned to the non-autonomous car (mean difference = −.52, $p = .007$, CI [-.90, −.14]), thus confirming H1a. On the other hand, participants assigned to the *energy efficiency frame* made more sustainable product choices than those in the *autonomy frame* condition (mean difference = 1.04, $p < .001$, CI [.65, 1.43]), confirming H2a. These participants also made more sustainable product choices compared to those in the control condition (mean difference = .52, $p = .006$, CI [.15, .89]).

9.1. Mediation analyses

We ran a multi-categorical mediation analysis (Hayes, 2017; model 4; 5000 bootstrap samples) that tested the impact that system framing exerted on participants' sustainable product choice. This analysis considered participants' abdication of responsibility and prosocial focus as continuously measured parallel mediators of such an effect. In this analysis, the non-autonomous condition was treated as the reference condition, and the "indicator" coding system was used, where X_1 referred to the autonomous system with *autonomy frame* while X_2 referred to the autonomous system with energy *efficiency frame*.

The analysis indicated that both the *autonomy frame* and the energy *efficiency frame* exerted significant positive effects on abdication of responsibility (respectively $b = .59$, $p = .003$; $b = .59$, $p = .004$), while only the *energy efficiency frame* had a significant positive effect on prosocial focus ($b = .76$, $p < .001$; Table 1). Controlling for the alleged mediators, the *autonomy frame* exerted a significant negative effect on sustainable product choice ($b = -.45$, $p = .019$). The inverse was true for the *energy efficiency frame*, which had a significant positive effect on sustainable product choice ($b = .47$, $p = .013$). The analysis also returned significant effects of abdication of responsibility ($b = -.12$, $p = .017$) and prosocial focus ($b = .15$, $p = .001$) on sustainable product choice.

In line with H1b, the results indicated that abdication of responsibility mediated the impact of the *autonomy frame* ($b = -.07$, 95 % CI: .164, −.010). In line with H2b, prosocial focus mediated the relationship between the *energy efficiency frame* and participants' choices ($b = .11$, 95 % CI: .032, .231).

10. Discussion

Study 1 confirms that users relate to autonomous systems in different ways depending on whether the systems are framed as "autonomy" or "energy efficient." The results indicate that highlighting an autonomous system's functionality incites users to trade off that system's sustainability for its performance and hence choose relatively unsustainable

Table 1
Study 1: Direct and indirect effects of the autonomous system's framing on sustainable product choice.

Variables	Coeff.	SE	*p*
Dependent variable: Abdication of responsibility (*Mediator* 1)			
Constant	2.96	.13	<.001
Autonomy frame (X_1)	.59	.20	.003
Energy efficiency frame (X_2)	.59	.20	.004
Dependent variable: Prosocial focus (*Mediator* 2)			
Constant	4.01	.15	<.001
Autonomy frame (X_1)	.04	.22	.857
Energy efficiency frame (X_2)	.76	.21	<.001
Dependent variable: Sustainable product choice (*Y*)			
Constant	3.19	.25	<.001
Autonomy frame (X_1)	−.45	.19	.019
Energy efficiency frame (X_2)	.47	.19	.013
Abdication of responsibility	−.12	.05	.017
Prosocial focus	.15	.05	.001
Indirect effects:	Coeff.	LLCI	ULCI
Effect of *Autonomy frame* on *Y* via *Abdication. of responsibility*	−.07	−.164	−.010
Effect of *Energy efficiency frame* on *Y* via *Abdication of responsibility*	−.07	−.150	−.007
Effect of *Autonomy frame* on *Y* via *Prosocial focus*	.01	−.065	.087
Effect of *Energy efficiency frame* on *Y* via *Prosocial focus*	.11	.032	.231

Note: $N = 367$; *X1* was coded as 0 = Non-autonomous system; 1 = Autonomous System with an Autonomy frame; *X2* was coded as 0 = Non-autonomous system; 1 = Autonomous System with an Energy efficiency frame.

versions of that system. This effect occurs because emphasizing an autonomous system's autonomy benefits motivates users to relinquish responsibility for this system's environmental impact. However, emphasizing an autonomous system's efficiency benefits can offset this effect and persuade users to make relatively more sustainable product choices. This latter effect occurs because an *energy efficiency frame* activates a prosocial focus, which increases sustainable product choice.

11. Study 2. comparing autonomous and non-autonomous systems

To gain a better understanding of whether the framing of autonomous systems influences users' sustainable product choices, Study 2 tested whether the hypothesized effects of the *autonomy frame* versus the *energy efficiency frame* on users' preferences for more or less sustainable versions of the system are specific to autonomous systems or also apply to non-autonomous systems. To assess the external validity of our findings, we used a different system (i.e., a cooking machine) and included two control conditions: a non-autonomous system with energy efficiency benefits and a non-autonomous system with autonomy benefits. To assess the ecological validity of our findings, this study employed an incentive-compatible design, where participants tried to achieve the best outcome for themselves, driven by their true preferences.

11.1. Procedure

Study 2 randomly assigned participants to one of four conditions (*autonomy no-automation*, *energy efficiency no-automation*, *autonomy frame with automation*, *energy efficiency frame with automation*), employing a between-subjects design that involved 283 online US crowd-workers (mean age = 39; SD = 11.30; 50 % females) recruited from Prolific Academic. We created four different descriptions of a cooking device: the two control conditions (featuring non-autonomous systems) presented this system as a cooking "tool," whereas the two treatment conditions (featuring autonomous systems) presented the system as a cooking "robot" (see Appendix 1 - Table A2 for details). All systems were functionally equivalent, but two descriptions highlighted the system's functionality, whereas the other two highlighted the system's efficiency. Our online survey instrument assigned each participant to one of these four different conditions.

11.2. Measures

After reading the system description, participants rated the system's perceived automation and sustainability. Then, all participants were informed that the system was available in two different versions with similar prices: one characterized by higher operational speed and higher energy consumption, the other by lower operational speed and lower energy consumption (see Appendix 1 - Table A3 for details). Our survey asked participants to indicate which of the two system versions they preferred. It invited them to choose carefully as, at the end of the study, they were entered into a lottery that might award them their choice. Then, participants completed the measures of abdication of responsibility ($\alpha = .91$) and prosocial focus ($\alpha = .94$) that we used in the previous studies. Before exiting the survey, participants provided their gender and age. Once data collection was completed, one participant was chosen at random and received the market value of the cooking machine, in the form of bonus payment on Prolific (approx. 250 euro). The participant was instructed they could purchase the cooking machine with the money if they so desired.

12. Results

12.1. Differences between conditions

Initially, we ran statistical tests on our manipulation checks, which confirmed that our manipulations were set-up correctly (see Appendix 3). Next, we ran a One-Way between-subjects ANOVA to investigate the effect of the independent variable "framing" on sustainable product choice, which highlighted a significant main effect, $F(3, 282) = 5.41$, $p < .001$, partial $\eta^2 = .55$. The planned multiple comparison tests showed that participants assigned to the *autonomy frame* condition made less sustainable product choices than participants presented with the *autonomy frame* of the non-autonomous version of the cooking machine (mean difference = −.188, $p = .015$, 95 % CI [-.34, −.04]), confirming once again H1a. Instead, participants assigned to the *energy efficiency frame* condition made more sustainable product choices than those in the *autonomy frame* condition (mean difference = .298, $p < .001$, 95 % CI [.15, .45]), again confirming H2a. Furthermore, participants assigned to the *energy efficiency frame* of the non-autonomous system made significantly more sustainable product choices than those assigned to the autonomous system with the *autonomy frame* (mean difference = .207, $p = .008$, 95 % CI [.06, .36]).

12.2. Mediation of abdication of responsibility and pro-social focus

We then implemented a mediation analysis (using Hayes' 2022 PROCESS macro, model 4) that considered system framing as a multicategorical independent variable with four levels: *autonomy frame* of the non-autonomous system (which was taken as the reference condition); *energy efficiency frame* of the non-autonomous system (*X1*); *autonomy frame* applied to the autonomous systems (*X2*); and *energy efficiency frame* applied to the autonomous systems (*X3*). Participants' sustainable product choice was a dichotomous dependent variable (coded as 0 = high-performance system, 1 = sustainable system), while abdication of responsibility and prosocial focus were included as mediators.

With respect to abdication of responsibility, the analysis yielded a significant positive effect for the *autonomy frame* of autonomous systems ($b = 1.20$, $p < .001$; Table 2) and for the *energy efficiency frame* condition ($b = .71$, $p = .006$), highlighting once again that the autonomous conditions induce abdication of responsibility regardless of autonomy or energy efficiency framing. The *energy efficiency frame* applied to either an autonomous or a non-autonomous system exerted significant positive effects on prosocial focus ($b = .82$, $p = .006$ and $b = 1.23$, $p < .001$, respectively). A significant negative effect emerged for the mediator abdication of responsibility on sustainable product choice ($b = -.65$, $p < .001$) and a significant positive effect of the mediator prosocial focus on sustainable product choice ($b = .68$, $p < .001$).

In line with H1b, the autonomous system with an *autonomy frame* exerted a significant negative indirect effect on participants' sustainable product choices through abdication of responsibility ($b = -.78$, 95 % CI: 1.411, −.381). The results also highlighted a significant positive indirect effect of the *energy efficiency frame* applied to the autonomous system on sustainable product choice through prosocial focus ($b = .83$, 95 % CI: .446, 1.391), further confirming H2b.

13. Discussion

Our second study confirms that autonomous systems motivate users to abdicate responsibility for these systems' environmental impact, and that autonomous systems framed around their *autonomy* benefits motivate users to make relatively unsustainable product choices. The study also confirms that framing an autonomous system around its *energy efficiency* benefits generates a prosocial focus, i.e., a shift in users' attention from the self to the broader environment of which they are a part. This latter effect persuades users to make relatively more sustainable

Table 2
Study 2: Effects of framing autonomous systems as autonomy or efficient.

	Statistical Results			
	b	*SE*	*t (z)*	*p*
Dependent variable: Abdication of responsibility (*Mediator 1*)				
Constant	4.34	.18	23.57	<.001
No Automation with Energy Efficiency Frame (*X1*)	.21	.26	.81	.417
Automation with Autonomy Frame (*X2*)	1.20	.26	4.61	<.001
Automation with Energy Efficiency Frame (*X3*)	.71	.26	2.76	.006
Dependent variable: Prosocial focus (*Mediator 2*)				
Constant	3.43	.21	16.29	<.001
No Automation with Efficiency Frame (*X1*)	.82	.30	2.73	.006
Automation with Autonomy Frame (*X2*)	.28	.29	.93	.354
Automation with Energy Efficiency Frame (*X3*)	1.23	.29	4.18	<.001
Dependent variable: Sustainable system choice (*Y*)				
Constant	−.56	.58	−.96	.337
No Automation with Energy Efficiency Frame (*X1*)	−.25	.44	−.58	.562
Automation with Autonomy Frame (*X2*)	−.71	.50	−1.42	.156
Automation with Energy Efficiency Frame (*X3*)	−.65	.44	.90	.371
Abdication of responsibility	−.65	.12	−5.58	<.001
Prosocial focus	.68	.11	6.17	<.001
Indirect effect:	*b*	*SE*	LLCI	ULCI
Effect of No Autom. with Energy Efficiency Frame on *Y* via Abdication of resp.	−.14	−.18	−.53	.19
Effect of Automation with Autonomy Frame on *Y* via Abdication of resp.	−.78	.26	−1.41	−.38
Effect of Automation with Energy Efficiency Frame on *Y* via Abdication of resp.	−.46	.23	−.99	−.10
Effect of No Autom. with Energy Efficiency Frame on *Y* via Prosocial Focus	.55	.24	.14	1.09
Effect of Automation with Autonomy Frame on *Y* via Prosocial Focus	.19	.22	−.23	.63
Effect of Sustainable Automation on *Y* via Prosocial Focus	.83	.24	.45	1.39

Note: *X1* was coded as 1 = No Automation with Energy Efficiency Frame; 0 = all other conditions; *X2* was coded as 1 = Automation with Autonomy Frame; 0 = all other conditions; *X3* was coded as 1 = Automation with Energy Efficiency Frame; 0 = all other conditions; *Y* was coded as 0 = High-performance product choice, 1 = Sustainable product choice.

product choices.

14. Study 3. delving into the effect of system positioning on sustainable system choices

Our third study extends our exploration from the previous investigations by delving deeper into the nuanced effect of differential system *framing* of automation on sustainable product choices. The study focused on a different type of system (i.e., an online algorithm) and observed participants' response to automation in a context characterized by high behavioral involvement (i.e., solving CAPTCHA tasks). This shift in context and system type serves to test whether the observed effects extend beyond physical autonomous systems. Additionally, we introduce users' concern for environmental issues, as operationalized by their biospheric value orientation, into our investigation. We hypothesize that this variable moderates the relationship between automation and sustainable product choices, as well as between prosocial focus and sustainable product choices. This addition enriches our comprehension of the variability in sustainable product choices in response to automation. In sum, Study 3 expands our prior work by further enhancing its external validity, focusing on real-world behavioral outcomes, and accounting for personal values related to environmental concerns. With these enhancements, we aimed to better understand the interplay between automation, sustainability, and individual consumer values.

14.1. Methods

Study 3 was a single-factor (framing: autonomy vs. energy efficiency) between-subjects online experiment. It focused on an online algorithm that could save users the tedious task of having to identify target images among numerous distractor images rich in visual information. A total of 330 users (M_{age} = 37; 42 % males), recruited through the "Prolific Academic" crowdsourcing platform, participated in this study. All participants were located in the UK, reported being over 18 years of age, and used English as a first language. As part of the introduction to the task, participants were informed that "everything they do digitally, such as Google searches, consumes energy, and therefore has a certain degree of environmental impact. The higher the amount of computing resources used during these tasks, the higher the level of energy consumption." The goal of this introductory phase was to give participants all the necessary information for them to make a fully informed decision later in the main task, when presented with an algorithm that could solve certain online tasks for them.

Next, participants were presented with "CrackerX," the beta-version of an algorithm that could autonomously solve image identification tasks commonly known as CAPTCHA tasks. At the global level, such tasks have relevant environmental implications because millions of users solve them every day (https://www.techuseful.com/captcha). Participants assigned to the *autonomy frame* condition read that this algorithm had been developed with the primary goal of "replacing humans in image identification tasks," whereas participants assigned to the *energy efficiency frame* condition read that the algorithm had been developed with the primary goal of "carrying out image identification tasks in an energy-efficient way" (see Appendix 1 - Table A4). Participants were then told that CrackerX had been developed in seven different versions, with increasing performance and decreasing sustainability.

14.2. Procedure

Participants were involved in three different trials of CrackerX, which were respectively aimed to identify cars, then traffic lights, then crosswalks. In each trial, they were given the chance to run their preferred version of CrackerX among seven possible options, with operational speed ranging from 21 s (lower-performing but more sustainable version) to 3 s (higher-performing but less sustainable version). Participants were instructed about the trade-off between the speed of resolution of the task and the amount of computing power required, as they read that "the faster the algorithm, the more computing resources it uses." Depending on their choice, participants were made to wait for a specific number of seconds while a loading screen was displayed. When the wait was complete, all the target images identified among the distractors displayed a large blue tick on them, and participants reviewed the algorithm's labor by accepting or rejecting the result (Fig. 2).

14.3. Measures

We aggregated the choices participants made in the three trials to build an index measuring their sustainable product choice. Following the three trials, participants rated their abdication of responsibility (α = .88) and their prosocial focus (α = .92) using adapted versions of the same scales that we used in Study 1 and Study 2. They also rated the algorithm's perceived sustainability using a single-item scale. Answers to these questions were measured through seven-point scales. We also measured participants' biospheric value orientation (α = .92) using a four-item scale drawn from Schwartz (1992), which served as an indicator of participants' involvement with environmental problems (see Appendix 4 for details). Finally, participants rated the extent to which they perceived the CrackerX algorithm as realistic (1 = Not at all credible, 7 = Very credible).

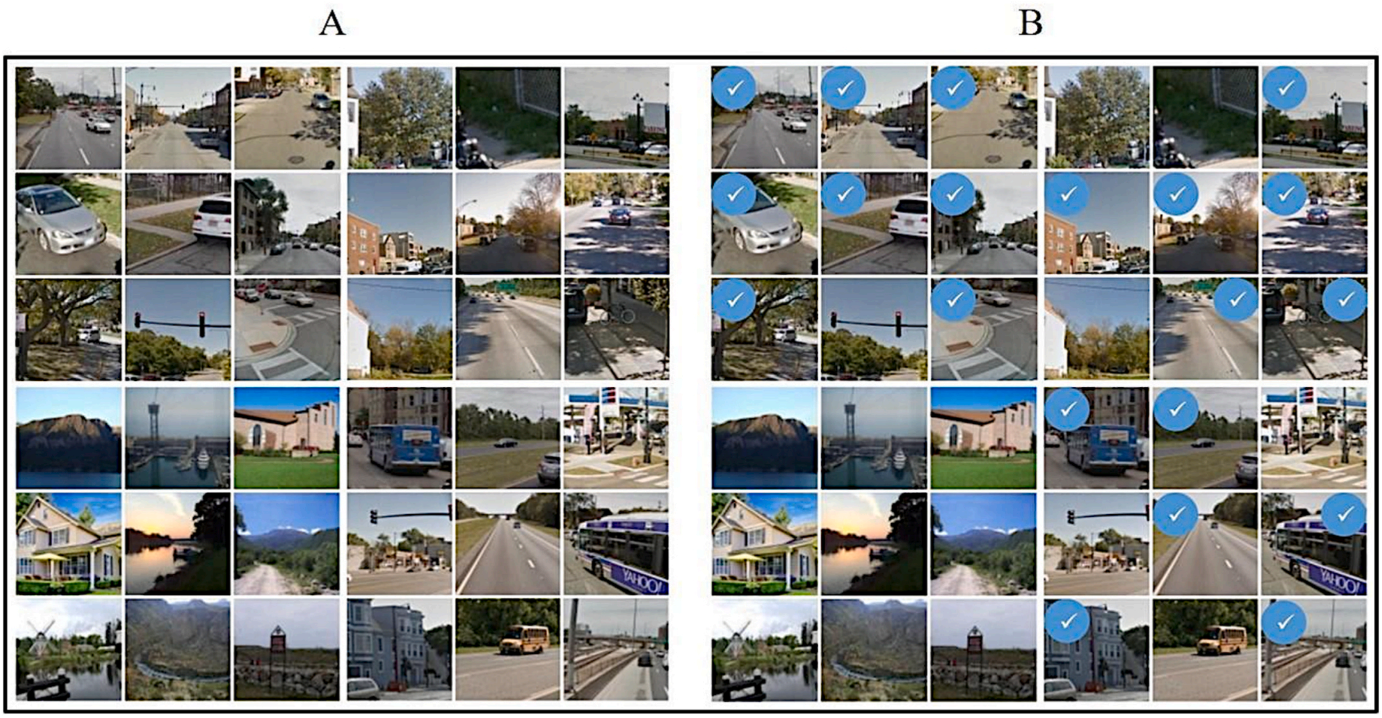

Fig. 2. Illustration of one of the three experimental trials requiring the identification of a target image. All the images were first displayed, and the participant was informed about the target image to be identified using the algorithm; in this case all images containing vehicles (Panel A). Participants chose their preferred version of the algorithm depending on its speed of resolution and resource consumption, then they waited for the algorithm to solve the task. The result of the algorithm was then displayed to the participant, where all target images identified by the algorithm contained a blue tick on the top left (Panel B).

15. Results

All participants rated CrackerX as a realistic online algorithm, as in both conditions the mean value of perceived credibility was significantly higher than the scale mid-point ($p < .001$, 95 % CI [4.64, 4.93]). Furthermore, credibility did not vary across the two experimental conditions (Autonomy = 4.78, $SD = 1.36$; Energy Efficiency = 4.79, $SD = 1.37$; $F(1, 328) = .002$, $p = .968$, CI [-.30, .29]). Participants assigned to the energy efficiency condition rated the algorithm as significantly more sustainable ($M = 4.87$, $SD = 1.17$) than their counterparts ($M = 4.27$, $SD = 1.18$, $F(1, 328) = 21.49$, $p < .001$, 95 % CI [.35, .86]). Participants did not differ in terms of how much they abdicated their responsibility ($p = .302$, 95 % CI [-.46, .14]). However, participants assigned to the energy efficiency framing condition reported a significantly stronger prosocial focus ($M = 4.50$, $SD = 1.53$) than their counterparts ($M = 3.31$, $SD = 1.69$, $F(1, 328) = 44.46$, $p < .001$, 95 % CI [.84, 1.54]) and made more sustainable product choices ($M = 3.30$, $SD = 1.47$) than their counterparts ($M = 2.66$, $SD = 1.31$, $F(1, 328) = 17.45$, $p < .001$, 95 % CI [.34, .95]). These results confirmed that framing automation as having an energy efficiency goal elicits a prosocial focus and can promote more sustainable product choices.

15.1. Mediation analysis

We ran a parallel mediation analysis (Hayes, 2017; model 4; 5000 bootstrap samples) that assessed the effect of a dichotomous independent variable (coded as: 1 = autonomy framing; 1 = energy efficiency framing) on sustainable product choice. This analysis considered abdication of responsibility and prosocial focus as parallel mediators of such an effect (Table 3). The independent variable did not affect abdication of responsibility ($b = .15$, $p = .302$), but it exerted a significant positive effect on prosocial focus ($b = 1.19$, $p < .001$, 95 % CI: .84, 1.54). As predicted, abdication of responsibility had a significant negative effect on sustainable product choice ($b = -.16$, $p = .003$, 95 % CI: .27, −.06), leading to less sustainable versions being preferred. On the other hand, prosocial focus had a significant positive effect on sustainable product choice ($b = .30$, $p < .001$, 95 % CI: .21, .39), leading to a preference for more sustainable versions of the algorithm (see Fig. 3). The energy efficiency (vs. autonomy) framing had a significant positive direct effect on sustainable product choice ($b = .31$, $p = .047$, 95 % CI: .00, .61). The analysis also revealed a significant positive indirect effect of autonomy vs. efficiency framing on sustainable product choice via prosocial focus ($b = .36$, 95 % CI: .217, .531), whereas the indirect effect via abdication of responsibility was not statistically significant ($b = -.02$, 95 % CI: .102, .011).

Table 3
Study 3: Direct and indirect effects determined by the framing of the search algorithm.

	b	S.E.	t	p
Dependent variable: Abdication of responsibility (*Mediator* 1)				
Constant	4.23	.24	17.54	<.001
Energy Efficiency Framing (*X*)	.15	.15	1.03	.302
Dependent variable: Prosocial focus (*Mediator 2*)				
Constant	2.13	.28	−7.56	<.001
Efficiency Framing (*X*)	1.19	.18	6.66	<.001
Dependent variable: Sustainable product choice (*Y*)				
Constant	2.05	.32	6.37	<.001
Energy Efficiency Framing (*X*)	.30	.15	1.99	.047
Abdication of responsibility (*Me1*)	−.16	.05	−2.98	.003
Prosocial focus (*Me2*)	.30	.05	6.63	<.001
Indirect effects of X on Y:	*b*	*S.E.*	*LLCI*	*ULCI*
Via Abdication of responsibility (*Mediator 1*)	−.02	.03	−.102	.011
Via Prosocial focus (*Mediator 2*)	.36	.08	.217	.531

Note: $N = 330$; X was coded as 0 = Autonomy Framing; 1 = Energy Efficiency Framing.

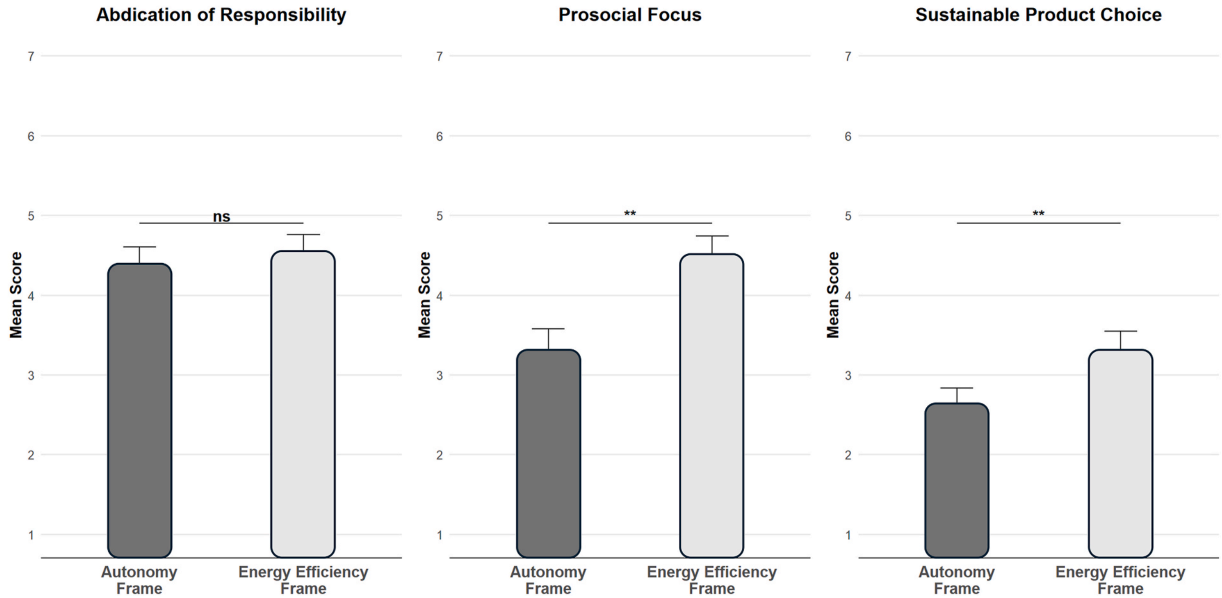

Fig. 3. Illustration of the effect of message framing. The chart represents levels of "Abdication of Responsibility", "Prosocial Focus" and "Sustainable Product Choice" depending on whether the autonomous system (i.e. an algorithm called "CrackerX") was communicated to participants using an Autonomy frame Vs. Energy Efficiency frame.

16. Discussion

The results of this study confirm that framing an autonomous system with an energy efficiency framing activates a prosocial focus. Due to this effect, systems presented with an energy efficiency framing (but not an autonomy framing) lead users to prefer more sustainable versions of the system.

17. General discussion

This research investigated whether the framing of autonomous systems affects the sustainable choices users make when presented with such systems. In particular, we focused on a "autonomy" framing, emphasizing the system's ability to function independently from the user, and on an "energy efficiency" framing, emphasizing the system's ability to optimally manage its resources. We show that when autonomous systems are framed as autonomy, users tend to prefer less sustainable versions of the system because they abdicate their responsibility for the environmental consequences of their usage. This also occurs when the system is framed as "efficient". However, in contrast to the detrimental effects observed when autonomy framing is employed, these effects are partly mitigated in this latter frame through the activation of a prosocial focus, prompting wider societal considerations that prioritize "the common good" (White et al., 2019), and, ultimately, more sustainable product choices. These results make two main theoretical contributions.

18. Framing autonomous systems: shifting user priorities toward sustainability

The findings demonstrate that framing autonomous systems as either autonomy or efficient influences user preferences for sustainable versions of these systems, with energy efficiency framing encouraging more sustainable product choices. We therefore extend the emerging literature on the ethical implications of users interacting with autonomous systems (e.g., Kopalle et al., 2021). While there is evidence that interacting with autonomous systems can lead to abdication of responsibility and reduce the likelihood of engaging in sustainable behaviors (e.g., Bonnefon et al., 2016; Jörling et al., 2019; Murtagh et al., 2015; Parasuraman & Riley, 1997), no study has examined whether autonomous systems, and in particular, the framing of these systems, affect the sustainable product choices users make regarding the system itself. Our results close this gap by showing that the framing of an autonomous system shapes user preference for more sustainable versions of that system. In particular, we show that emphasizing the system's ability to function autonomously, using a "autonomy" framing, encourages the user to trade-off sustainability benefits for power and performance benefits. This finding extends previous work on trade-offs between sustainability benefits and other benefits (Luchs and Kumar, 2017) by identifying how message framing impacts these trade-offs in the specific context of autonomous systems. Our findings reveal that framing can be an effective means to guide users to prioritize sustainability over other benefits, such as power or performance.

Our findings reveal that users are willing to sacrifice autonomy benefits (e.g., system performance) in favor of sustainability when systems are framed with an emphasis on energy efficiency. This highlights a critical mechanism through which framing can encourage sustainable behavior, as users shift their priorities from self-serving goals to societal benefits due to activating a prosocial focus (Farmer et al., 2017). By demonstrating the importance of aligning system's framing with environmental objectives, this research broadens findings in sustainability research (e.g., Paparoidamis et al., 2019) and expands their applicability to the rapidly evolving field of autonomous systems.

Our findings also deepen our understanding of the effects of automation on perceptions of responsibility. Previous studies have documented that individuals often perceive a reduced sense of responsibility when interacting with autonomous systems or services, such as self-driving cars (Bonnefon et al., 2016; Gill, 2020), flight-assist systems (Parasuraman & Manzey, 2010; Parasuraman & Riley, 1997), and robots in general (Jörling et al., 2019). Other studies have highlighted that this reduced responsibility can lead to problematic behaviors, such as excessive gambling (Armstrong et al., 2017) or overeating (Hagen et al., 2017). We extend these findings by demonstrating that automation also affects individuals' feelings of environmental responsibility, making them feel less accountable for the environmental impact of these systems. To the best of our knowledge, we show for the first time that a diminished feeling of responsibility leads users to prefer less sustainable versions of autonomous systems. This decrease in feeling of responsibility appears unaffected by how the system's benefits are presented (autonomy or energy efficiency framing). This suggests that users may harbor deeply rooted beliefs about automation's primary advantages, which linguistic strategies may struggle to alter.

Despite its relevance, this topic has received limited attention, and research into consumer responsibility for the environmental consequences of autonomous systems remains sparse.

19. Practical implications

The findings of this research have several practical implications for developers and policymakers seeking to promote sustainability in the design and adoption of autonomous systems. First, developers and marketers should prioritize efficiency-focused framing when promoting autonomous systems to encourage sustainable choices. Highlighting how these systems optimize resource management can activate users' prosocial focus, motivating them to prioritize societal benefits over self-serving utility. Conversely, an emphasis on a pure autonomy framing should be avoided, as it may lead users to neglect their environmental responsibility, potentially resulting in less sustainable choices. Policymakers could also play a pivotal role by encouraging the adoption of sustainability-focused autonomous systems and incentivizing businesses to adopt responsible communication strategies. Policies could mandate the inclusion of sustainability information or standardize how energy efficiency elements are presented to consumers. Finally, this research highlights the need to strengthen users' sense of responsibility for the outcomes of the autonomous systems they use. Although this lies beyond the scope of the current study, policymakers and researchers in the field are encouraged to explore ways to enhance this perceived responsibility, potentially fostering positive effects on users' sustainable decision-making.

20. Limitations and future research

This research features limitations that indicate avenues for future investigations. This research features limitations that indicate avenues for future investigations. First, we acknowledge that Studies 1 and 2 relied predominantly on scenario-based experimentation, and that all three studies employed non-representative online samples. Future research is therefore recommended to test our hypotheses in real consumption contexts, using more diverse or representative populations. Second, while our studies examined sustainable product choices, future research could investigate the effect that new autonomous systems have on system usage to test whether abdication of responsibility ultimately results in system overuse. For instance, in the case of autonomous cars, the fact that they require less attention when driving may tempt users to travel more frequently or cover longer distances (Taiebat et al., 2019) because they feel less responsible for the car's functioning. Similarly, users might be tempted to overuse advanced machines, such as robotic bartenders, which can prepare over 100 coffees per hour and remain active 24/7 (Manson, 2021). For this reason, such robots should keep track of how many drinks they serve each customer and avoid over-serving the same person. These considerations also apply to energy-efficient smart home devices (e.g., smart thermostats), which, by creating the illusion of responsible energy use, may ultimately lead to increased energy consumption, exacerbating the so-called "rebound effect" (i.e., the increase in consumption following the adoption of a more efficient technology; Walzberg et al., 2020).

Third, the consequences of framing a new autonomous system with an autonomy or energy-efficiency frame might be influenced by the perceived usefulness of the system. Users mainly assess the value of new systems based on its perceived usefulness (Li et al., 2015), and when applied to autonomous systems, perceived usefulness is likely intertwined with abdication of responsibility: the more the system is perceived as being able to take care of effortful or boring tasks, the more it will be seen as useful, and in turn users may abdicate more responsibility for the system's energy consumption.

Interestingly, while this project focused on abdication of responsibility, which was measured using a scale, the mid-range average scores on this variable, observed in all studies, suggest participants experienced a certain ambiguity surrounding who should be held accountable for the energy-related consequences of autonomous systems. Past research has shown that ambiguity in tasks and contexts acts as a moral buffer, or as moral wiggle room (Dana et al., 2007), that can help individuals justify unethical choices, such as cheating and lying (Pittarello et al., 2015; Puntiroli et al., 2025). Any ambiguity as to who is responsible between the user and the system, for the energy-related consequences of the system's tasks, should reduce participants' proclivity to acting sustainably, which aligns with our findings. We therefore encourage researchers in this field to consider that the concept of "diffused responsibility" (e.g. Bandura, 1999), or "abdication of responsibility" (e.g. Murtagh et al., 2015) may all stem from a sense of ambiguity as to which agent should be held accountable.

Future studies could also test whether the effects determined by different framings of autonomous systems vary based on consumption contexts (e.g., public versus private). Past research (Griskevicius et al., 2010) suggests that higher versus lower social visibility might significantly affect users' willingness to make sustainable choices.

CRediT authorship contribution statement

Michael Puntiroli: Writing – review & editing, Writing – original draft, Visualization, Validation, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Giovanni Pino:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Conceptualization. **Valéry Bezençon:** Writing – review & editing, Supervision, Resources, Conceptualization. **Linda Lemarie:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Conceptualization.

Ethics

Ethical approval for the research was granted by the ethics committee of the institution.

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.

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Appendix 1. Experimental stimuli

Table A1
Study 1 stimuli

Non automation condition	Autonomy framing	Energy Efficiency framing
Imagine that you are at your car dealer because you intend to change your old car with a new model. When you are in the store one of the salespeople shows you a particular model that you expressed interest in. It is a car that incorporates cutting-edge technology enabling you to manage headlight intensity, windscreen wiper speed, air conditioning, and many other functions. The car is available in three different colors and versions.	Imagine that you are at your car dealer because you intend to change your old car with a new model. When you are in the store one of the salespeople shows you a particular model that you expressed interest in. It is a car that incorporates cutting-edge technology enabling it to automatically manage headlight intensity, windscreen wiper speed, air conditioning, and many other functions. This technology has been primarily developed to *increase the car's practicality.* For this reason, this car is considered one of the most *functional* cars on the market. The car is available in three different colors and versions.	Imagine that you are at your car dealer because you intend to change your old car with a new model. When you are in the store one of the salespeople shows you a particular model that you expressed interest in. It is a car that incorporates cutting-edge technology enabling it to automatically manage headlight intensity, windscreen wiper speed, air conditioning, and many other functions. This technology has been primarily developed *to reduce the car's energy consumption.* For this reason, this car is considered one of the most *sustainable* cars on the market. The car is available in three different colors and versions.

Table A2
Study 2 stimuli

	Autonomy framing	Energy Efficiency framing
Non-autonomous systems	This is the ChefBot by Create, a *functional* kitchen tool that will facilitate many of your daily tasks, such as cutting vegetables or stirring soups and sauces. The Chefbot comes with different cooking programs. Based on your ingredients, you can select the most suitable one. You can adjust blade rotation speed in order to *speed-up meal preparation*. So, you will manage the entire cooking processes in a *time*-efficient way. You can also adjust the cooking temperature in order to reduce electricity consumption. Most importantly, with the ChefBot you will *free-up your time*!	This is the ChefBot by Create, an *eco-friendly* kitchen tool that will facilitate many of your daily tasks, such as cutting vegetables or stirring soups and sauces. The Chefbot comes with different cooking programs. Based on your ingredients, you can select the most suitable one. You can easily adjust the cooking temperature in order to *reduce electricity consumption*. So, you will manage the entire cooking process in an *energy*-efficient way. You can also adjust blade rotation speed in order to speed-up meal preparation. Most importantly, with the ChefBot, you will *minimize your impact on the environment*!
Autonomous systems	This is the ChefBot by Create, a *functional* kitchen robot that will facilitate many of your daily tasks, such as cutting vegetables or stirring soups and sauces. The ChefBot uses artificial intelligence to automatically recognize ingredients and select the most suitable cooking program. It automatically adjusts blade rotation speed in order to *speed-up meal preparation*. So, it manages the entire cooking processes in a *time*-efficient way. It can also adjust the cooking temperature in order to reduce electricity consumption. Most importantly, the ChefBot will *free-up your time*!	This is the ChefBot by Create, an *eco-friendly* kitchen robot that will free you from many daily tasks, such as cutting vegetables, or stirring soups or sauces. The ChefBot uses artificial intelligence to automatically recognize ingredients and select the most suitable cooking program. It automatically adjusts the cooking temperature in order to *reduce electricity consumption*. So, it manages the entire cooking process in an *energy*-efficient way. It can also adjust blade rotation speed in order to speed-up meal preparation. Most importantly, the ChefBot will *minimize your impact on the environment*!

Table A3
Study 2: Information regarding the system versions displayed to study participants

Features	CB-2368M	CB-2368L
Power (W)	600	1400
Energy consumption in stand-by mode (Wh)	.7	2.3
Average defrosting speed (minutes)	20	12
Average defrosting speed (minutes)	35	20

Table A4
Study 3 stimuli

Autonomy framing	Energy Efficiency framing
The CrackerX algorithm you are about to try out can help you complete different types of image recognition tasks (Captcha tasks) *faster* than if you solved them entirely by yourself. CrackerX optimizes processes thanks to its ability to simultaneously access and analyze multiple information sources. In doing so, it integrates much more smoothly than similar algorithms. Therefore, CrackerX contributes to making the online world a more *functional* place.	The CrackerX algorithm you are about to try out can help you complete different types of image recognition tasks (Captcha tasks) using *less electricity* than if you solved them entirely by yourself. CrackerX optimizes processes thanks to its ability to simultaneously access and analyze multiple information sources. In doing so, it consumes much less energy than similar algorithms. Therefore, CrackerX contributes to making the online world a more *eco-friendly* place.

(*continued on next page*)

Table A4 (*continued*)

Autonomy framing	Energy Efficiency framing
Click "Next" to generate a set of images for the Captcha task. The task consists of selecting all images with [Cars/Traffic Lights/Crosswalks]	Click "Next" to generate a set of images for the Captcha task. The task consists of selecting all images with [Cars/Traffic Lights/Crosswalks]
Cracker X comes in different versions that have different characteristics. These are described below.	Cracker X comes in different versions that have different characteristics. These are described below.
[all images displayed]	[all images displayed]
Please indicate which version of the algorithm you would like to use. The faster the algorithm the more computing resources it uses.	Please indicate which version of the algorithm you would like to use. The faster the algorithm the more computing resources it uses.

Appendix 2. Study 1 *descriptive analyses and manipulation checks*

Participants assigned to the non-autonomous condition perceived the car as significantly less autonomous than participants assigned to the *autonomy framed* autonomous car ($p < .001$, CI [−1.27, −.63]) and the *energy efficiency framed* autonomous car ($p < .001$, CI [−1.43, −.80]. Perception of automation did not change between the latter two groups of participants ($p = .315$, CI [-.50, .16]). Participants assigned to the *energy efficiency framed* autonomous car rated this system's sustainability significantly higher than participants assigned to the non-autonomous car ($p < .001$, CI [.70, 1.33]) and the *autonomy framed* autonomous car ($p < .001$, CI [.51, 1.17]). Perceived sustainability did not vary across these latter two conditions ($p = .276$, CI [-.50, .14]). Table A5 displays further details about participants' responses to the tested system.

Table A5
Study 1: Descriptive statistics

Variables:	Experimental conditions					
	No automation		Autonomy frame		Energy efficient frame	
	Mean	SD	Mean	SD	Mean	SD
Perceived automation	4.14	1.32	5.09	1.27	5.26	1.22
Perceived energy efficiency	4.30	1.23	4.48	1.42	5.32	1.18
Abdication of responsibility	2.96	1.46	3.55^{a}	1.71	3.49^{a}	1.49
Prosocial focus	4.01^{a}	1.78	4.05^{a}	1.75	4.77	1.60
Sustainable product choice	3.43	1.47	2.91	1.55	3.95	1.49

Note: $N = 367$. Mean values sharing the same superscript in each row do not significantly differ from each other.

Appendix 3. Study 2 *descriptive analyses and manipulation checks*

Participants assigned to the robotic versions of the cooking device rated it as significantly more "automated" ($M = 5.76$, $SD = 1.02$) than participants assigned to the other two experimental conditions ($M = 5.14$, $SD = 1.19$, $p < .001$, 95 % CI [.37, .89]). Participants assigned to the two non-automated conditions scored significantly lower on abdication of responsibility ($M = 4.45$, $SD = 1.45$) than participants assigned to the two automated conditions ($M = 5.29$, $SD = 1.64$, $p < .001$, 95 % CI [−1.21, −.48]). The average value of perceived automation and abdication of responsibility did not vary across the two non-automated conditions (Δ perceived system automation = .715, 95 % CI [-.33, .47]; Δ abdication of responsibility = .389, 95 % CI [-.27, .70]). Furthermore, these two variables had substantially identical values in the two automated conditions (perceived system automation = .717, 95 % CI [-.40, .28]; abdication of responsibility = .075, 95 % CI [-.05, 1.02]).

Participants assigned to the "efficiency frame" conditions rated the cooking device as significantly more "efficient" ($M = 4.58$, $SD = 1.30$) than their counterparts ($M = 4.03$, $SD = 1.39$, $p = .001$, 95 % CI [.23, .86]). The former also reported a higher prosocial focus ($M = 4.46$, $SD = 1.72$) than their counterparts ($M = 3.57$, $SD = 1.18$, $p < .001$, 95 % CI [.48, 1.31]). The average value of perceived sustainability and prosocial focus did not vary across the two "autonomy frame" conditions (perceived system efficiency = .720, 95 % CI [-.55, .38]; prosocial focus = .369, 95 % CI [-.88, .33]). Furthermore, these two variables had substantially identical values in the two "efficiency frame" conditions (perceived system efficiency = .311, 95 % CI [-.65, .21]; prosocial focus = .150, 95 % CI [-.98, .15]). Table A6 provides full pattern of descriptive information.

Table A6
Study 2: Means and standard deviations of the main study variables

	Experimental study conditions							
	Autonomy frame without automation		Efficiency frame without automation		Autonomy frame with automation		Efficiency frame with automation	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Perceived automation	5.10^{a}	1.32	5.17^{a}	1.04	5.73^{b}	1.13	5.79^{b}	.91
Perceived energy efficiency	3.99^{a}	1.22	$4.46^{b, c}$	1.39	$4.07^{a,b}$	1.55	$4.68^{a, c}$	1.20
Abdication of responsibility	4.34^{a}	1.53	4.56^{a}	1.38	5.54	1.44	5.05	1.28
Prosocial focus	3.43^{a}	1.79	4.25^{b}	1.88	3.71^{a}	1.84	4.67^{b}	1.53

Note: $N = 283$; in each row, mean values sharing the same superscript do not significantly differ from each other.

Appendix 4. Main measurement scales

Abdication of responsibility for energy consumption (adapted from Murtagh et al., 2015; (1 = Strongly disagree, 7 = Strongly agree) Employed in Study 1.

- With that new car, I would not need to be responsible for fuel consumption.
- That new car will take responsibility for automatically controlling fuel consumption.
- With that new car, I would not need to make the effort to control fuel consumption.

Employed in Study 2.

- With that new floodlight, I would not need to be responsible for energy consumption.
- That new floodlight will take responsibility for automatically controlling energy consumption.
- With that new floodlight, I would not need to make the effort to control energy consumption.

Employed in Study 3.

- With CrackerX, I would not need to be responsible for controlling consumption of computing resources.
- CrackerX will take responsibility for automatically controlling consumption of computing resources.
- With CrackerX, I would not need to make the effort to control consumption of computing resources.

Prosocial focus (adapted from Farmer et al., 2017; (1 = Strongly disagree, 7 = Strongly agree)
When deciding on that car [floodlight/algorithm] my thoughts were, at least in part, directed at …

- … protecting and improving the quality of our natural environment.
- … minimizing my negative impact on the natural environment.
- … creating a better life for future generations.

Biospherism (adapted from Steg et al., 2014, in turn adapted from Schwartz, 1992)
Please rate how important each value is for you as a guiding principle in your life using a score from 1 to 7 (where 1 is "Not important at all" and 7 is "Extremely important").

- Protecting the environment (preserving nature).
- Preventing pollution (protecting natural resources).
- Respecting the earth (harmony with other species).
- Unity with nature (fitting into nature).

Data availability

Data will be made available on request.

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