PLATE
Product Lifetimes And The Environment

Nudging as a strategy to prevent behavioural rebound effects in the early phases of design

Anna Lodberg Mammen[a], **Emilie M. D. Hartvigsen**[a], **Imke G. H. Van der Loo**[a], **Daniela C. A. Pigosso**[a]

a) Technical University of Denmark (DTU), Department of Civil and Mechanical Engineering, Lyngby, Denmark

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Abstract: Despite the recognition that ca. 50% of the potential environmental gains of sustainability-oriented interventions are offset by rebound effects (RE), effective strategies that can prevent the occurrence of rebound effects are currently missing. To address this gap, this paper explores how nudging can be used to prevent RE during the early phases of design of products, product/service-systems and socio-technical systems. Through a Systematic Literature Review, 23 nudges that have the potential to promote sustainable behaviour were identified and subsequently classified into four categories: 'Decision information' (e.g. descriptive norms), 'Decision structure' (e.g. defaults), 'Decision assistance' (e.g. pre-commitment), and 'Miscellaneous' (e.g. priming). The identified nudges served as the foundation for the development of a novel design tool that can support the selection of nudges to prevent RE in the early phases of design, with indication of potential additional RE emerging from the implementation of the selected nudges. In addition to the development of the tool, this study mapped existing research gaps that can guide further research in the field.

Introduction

While design for sustainability is receiving more attention, the potential sustainability gains are not being achieved due to rebound effects (Otto et al, 2014). Rebound effects (RE) are systemic responses triggered by sustainability-oriented innovations (Guzzo et al, 2024) that offset ca. 50% of their potential environmental gains (Brockway et al, 2021). Up until now, research has mostly focused on examining the effect size of the rebound effects. Nevertheless, knowledge on how to prevent rebound effects is still limited.

As pointed out by Osbaldiston & Schott (2012) and DaSilva (2023) nudges can be an effective tool in enhancing and promoting pro-environmental behaviour. Nudges are simple yet low-cost interventions that can alter people's behaviours without applying a force of hand or significantly changing monetary incentives (Thaler & Sunstein, 2009).

Although nudging has demonstrated success in promoting sustainable behaviours, their application within the field of sustainable design to prevent rebound effects remains unexplored and a comprehensive overview is lacking. Therefore, this paper aims to address the following research question "How to support designers to select nudging strategies to prevent RE in the early phases of design?". Focus on the early phases of design is chosen as approximately 80% of a product's environmental profile is determined in this phase (McAloone & Bey, 2009). The research question is addressed by: (1) identifying and categorising nudges to be applied to sustainable design; (2) evaluating how the nudges relate to behavioural rebound mechanisms (i.e., preventing or increasing); and finally (3) creating a tool to support designers to prevent RE of products, product/service-systems and socio-technical systems.

Methodology

This paper applied the Design Research Methodology of Blessing & Chakrabarti (2009), especially suited for developing academic results applicable to design support (Blessing & Chakrabarti, 2009). The Design Research Methodology includes three main phases: (1) Descriptive Study I (DSI); (2) Prescriptive Study (PS); and (3) Descriptive Study II (DSII).

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Descriptive Study I

A Systematic Literature Review (SLR) was conducted to examine how nudging can be used to increase sustainable behaviour. Using Scopus as the scientific database, the following search string was applied: TITLE("nudg*" OR "behavi* design" OR "cognitive psycholog*" OR "behavi* experiment" AND "sustain*" OR "environment*" OR "climate*" OR "circular*" OR "green*"). Studies that were published before 1999, are non-English, and refer to a different domain (e.g. chemistry, medicine, mathematics etc.) were excluded.

The search string provided 138 studies, which were filtered based on two steps (i.e., reading article title, keywords, abstract; and reading full text) while applying **three** inclusion criteria: (1) sustainability relevance; (2) relation to product/system; and (3) nudging and/or behavioural relevance. This resulted in the identification of 51 relevant studies (for full overview see: https://doi.org/10.11583/DTU.28513265.v1.

The 51 studies led to the identification of 174 nudges. After merging duplicate nudges, a final list of 23 nudges were categorised based on the choice architecture categories and techniques of Münscher et al (2016):

- Decision information: nudges that target decision-relevant information without altering options
- Decision structure: nudges that alter the arrangement of options and the decision-making format
- Decision assistance: nudges that provide decision assistance to achieve given intentions

A fourth category, Miscellaneous, was applied to nudges that did not fit into the existing categories.

Lastly, the nudges were categorised based on their effectiveness, amount of evidence and ease of implementation. The effectiveness was evaluated through primary evidence of whether a specific nudge was deemed effective (supported evidence), mixed effective (context specific or uncertain evidence) or ineffective (not supported evidence) (Formula 1). The evidence was calculated as shown in Formula 2. Finally, the ease of implementation of each nudge was estimated based on the expected 'number of stakeholders involved', the 'implementation time' and the 'implementation cost'.

$$\frac{no.of\ effective\ sources+\frac{no.of\ mixed\ effective}{2}}{no.of\ sources\ in\ total} \cdot 100 \qquad (F1)$$

$$\frac{no.of\ sources\ mentioning\ nudge}{no.of\ sources\ of\ most\ mentioned\ nudge} \cdot 100 \qquad (F2)$$

The actual percentage was calculated by weighing the nudges against each other; scoring each nudge either 1 or 0 against each other. The higher the score in total, the easier we assumed it is to implement the nudge.

The connection between the identified nudges and behavioural rebound mechanisms was synthesised by answering the underlying question; 'Can the nudge counteract a given behavioural rebound mechanism?' through an initial analysis by the authors and collective workshop. The analysis was carried out based on 15 behavioural rebound mechanisms (Pigosso & Van der Loo, 2024). After which, only the nudges assumed to be most effective in counteracting RE were selected for the final analysis, e.g. 'loss framing' nudges can counteract 'moral licensing' RE by motivating PEBs and preventing moral credit collection.

Prescriptive Study

The Prescriptive Study focused on synthesising the insights from the Descriptive Study I into a design tool for the selection of relevant nudges to prevent RE.

The tool development started with desk research of existing tools and defining a requirement specification. The requirements acted as a base to move into idea generation, where silent brainstorms led to the creation of seven distinct ideas. Ranking these on feasibility vs. fidelity in a matrix, four were deemed promising. Creating a better basis for choosing, the four ideas were conceptualised and evaluated with pros and cons. Considering the requirements, a Pugh matrix was used to weigh the concepts. Once a concept was chosen, detailing begun. The tool was prototyped and finalised in Excel.

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Descriptive Study II
The final phase of the study covered an evaluation of the tool. To enable specific feedback from different perspectives, the evaluation involved four researchers in the field of RE, and two design engineer students with no prior knowledge of RE. Feedback was collected with the aid of two tests to evaluate: (1) general usability of the tool; and (2) the usefulness of the tool. In the first test, the users were asked to use the tool to identify relevant nudges, after a product/service-system within clothing and the related RE's were provided. The second test additionally examined the user's ability to select relevant RE before choosing the nudges appropriately for the same design case. After both tests, a survey to evaluate usability and usefulness was administered. The results of the evaluations were used to iterate on the functionality and content of the tool.

Results

Descriptive Study I – Data analysis and synthesis

Strengths and gaps in literature
The systematic literature review provided an overview of the tendencies in research on nudging and sustainability, along with the strengths and gaps. The majority of research on nudging consisted of articles with experimental studies based on quantitative data (Figure 1). This provides a good foundation of evidence from primary sources, although doubts could arise whether the conclusions are generalisable due to the typical isolated nature of experiments.

The selected studies were also evaluated based on the addressed context (Figure 2). Existing research mostly covered the 'Food' sector on a product level (i.e., 17%). The most addressed sustainability type was 'efficiency', which means that there exists a gap in research on 'sufficiency' and 'effectiveness' that still remains relatively untouched. The total number of sources represented in this model covered 45 of the 64 reviewed in the SLR, as the other 19 sources did not examine specific design process or research strategies, indicating a gap.

Figure 1. Document type, main research methodology, and quantitative vs. qualitative methods.

Nudging strategies
Figure number 3 illustrates the consolidated 23 specific within four main categories: 'Decision information', 'Decision structure', 'Decision assistance' and 'Miscellaneous'.

The figure clearly indicates that 'social comparison' (especially 'descriptive norms'), 'labelling', 'defaults', and 'pre-commitment' appear to be well researched and tested, whereas other nudges like 'active choice', 'self-nudge', 'single-event nudge', and 'personalised nudge' are mentioned only once and would require additional research to test and validate their effectiveness properly. All nudges alongside a description and an example are summarised in Table 1.

The output of the comparison of the nudges can be seen in Figure number 4.

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Figure 2. Distribution of sectors on design level and type of sustainability.

Nudging with 'defaults' is the most researched in literature. 'salience' and 'graphics' are the easiest to implement, while feedback-based nudges are very difficult to implement. 'sescriptive norm comparison' and 'option-related effort' are assumed to be highly effective, and nudges such as 'active choice' and 'single-event' less so. Overall, 'static descriptive norm comparison', 'defaults', and 'salience' are assumed to be strong on all parameters, while 'self-nudge' and 'personalised nudge' are weak.
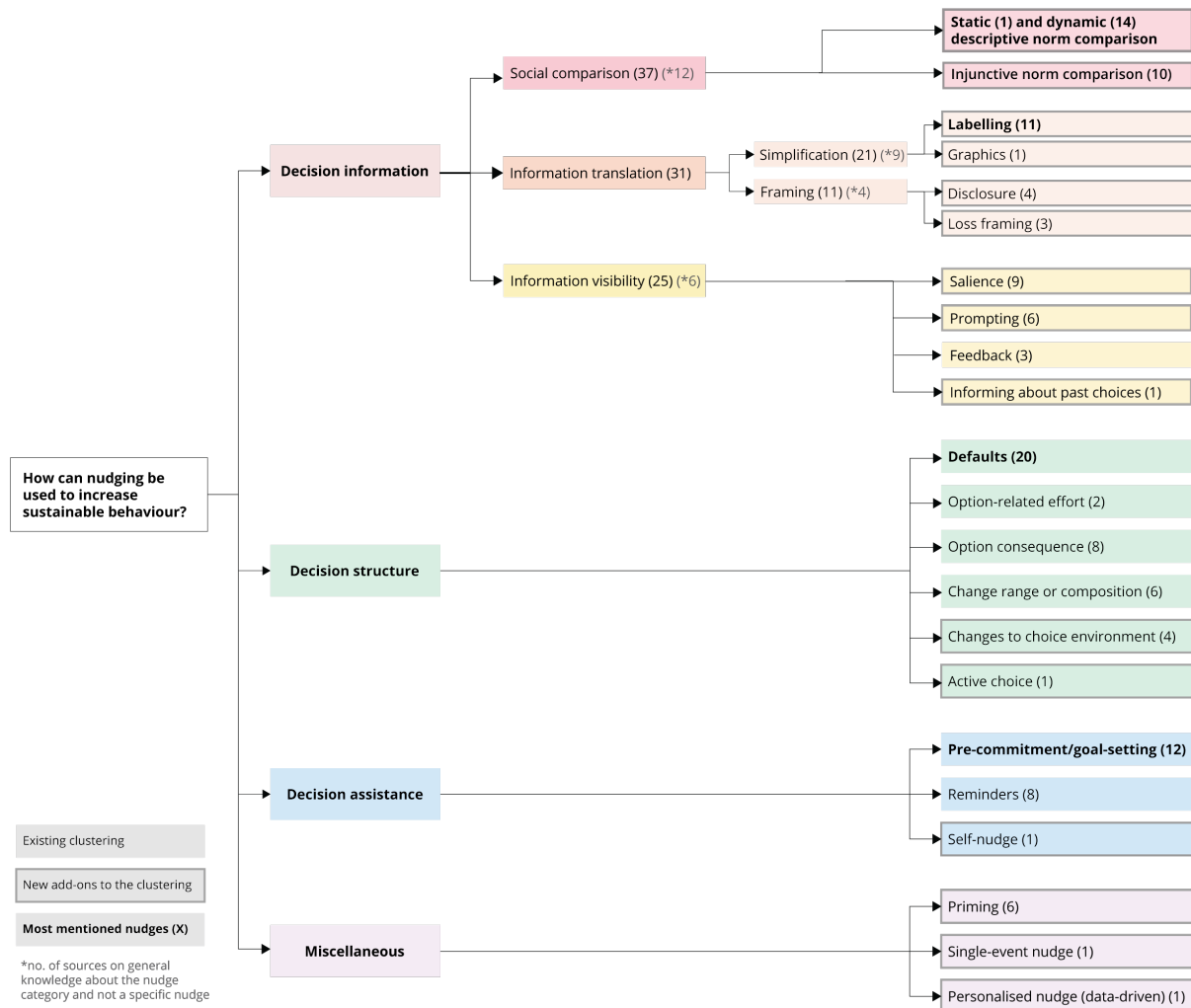
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Figure 3. Nudges (refer to https://doi.org/10.11583/DTU.28513265.v1 to see the references)

Nudge strategy	Description of nudge strategy	Example
Decision information		
Social comparison Comparison with social norms, which are rules and standards that are understood by members of a group, can guide/constrain behaviour without the force of law due to humans wish to "do what others are doing".		
Static descriptive norm comparison	Information of "what is done"	Displaying "60% of the customers today chose green food options"
Dynamic descriptive norm comparison	Information about an increasingly changing norm over time	Displaying "More and more people are choosing green food options"
Injunctive norm comparison	Information of "what should be done" nudges the user based on ones morale	Displaying "Take responsibility; we should all contribute to saving the environment together"

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Information translation: Simplification		
Simplifying information by "making it easy" and removing barriers increases the acceptance of procedures by users.		
Labelling	A simple and easy-to-understand way of showing environmental information	Marking the food products with the fairtrade label
Graphics	Graphics, symbols, or a notice of warning simply convey information to users	Using icons to show good/bad products, simplifying environmental information

Information translation: Framing		
By presenting the same information in different ways/frames, people tend to decide differently.		
Disclosure	Framing information based on disclosure and transparency to convey "the truth"	Disclosing the actual environmental footprint of food on the packaging
Loss framing	People prefer to avoid losses - therefore, framing info as losses can motivate users to certain choices	Comments to your online shopping basket: "This product increases your footprint by 10%"

Information visibility		
Nudges that make users notice something important by putting visual emphasis on it, which in turn can nudge the user to taking certain choices.		
Salience	Making information stand out with contrast, colours, sizing, and nature pictures	Highlighting sustainable options by increasing their size in an online the store
Prompting	Subtle and noncoercive guidance messages pushed to the user	When adding products in your basket, prompt: "Switch to a more sustainable option?"
Feedback	Receiving feedback can support and nudge users to reflect on their actions	Every month, the user receives information about their energy consumption this month
Information about past choices	Making past choices visible to the user can increase accountability	At check-out, show: "Previous basket CO2 footprint 10.1 kg – now 17.6 kg!"

Decision structure		
Defaults	Setting the preferred choice as a pre-selected default can influence the end choice if the user takes the path of least resistance	Setting most sustainable option in a product-configurator as the default
Option-related effort	Making small changes in the effort required to select an option	Placing sustainable options on the same online shopping tab, reducing effort of locating them
Change range or composition	Changing the placement of an option and the alternatives presented can alter relative attractiveness	Setting the most sustainable options in a product-configurator as the first ones
Option consequence	Changes in external financial or social consequences can nudge users to take certain choices	Rewarding customers with green badges or financial incentives for choosing green food options

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Changes to choice environment	Physical changes to choice environment (e.g., simplifying information, removing frictions) can influence decisions	Placing sustainable products in the supermarket on the shelf at eyesight
Active choice	When consumers have to make an explicit choice (i.e., no default is impolemented), users can reflect more and take conscious choices	Having no default option in a product-configurator before the user actively chooses
Decision assistance		
Pre-commitment (goal-setting)	Facilitate goal-setting as people are more likely to behave in line with their goals if they committed beforehand.	Allowing users to commit to keeping their CO_2 footprint below a threshold
Reminders	Timely and repeated reminders work as a nudge to make individuals conscious of what they are supposed to accomplish	Reminder at 7.30 each work day: "turn off light before leaving"
Self-nudge	Self-nudging aims to explain why users might fail to reach their goals and provide info and mechanisms of how to overcome these barriers - mixing feedback and framing	Providing free reusable coffee cups reducing single-use cups and reminders to keep using them
Miscellaneous		
Priming	Preparing people for their choice by simulating feelings and thoughts through introducing specific topics, moods, or the consequences of their decision before it takes place	Posters on the way to a canteen about consequences of eating meat
Single-event nudge	One-time activity that changes the specific behaviour for good	An annual bike-to-work event, where participants are nudged to continue biking afterwards
Personalised nudge (data-driven)	Personalised intervention mechanisms based on previously collected data that informs and nudges the user to take certain choices	Providing citizens with a personalised map of the most sustainable route home

Table 1. Nudges (refer to https://doi.org/10.11583/DTU.28513265.v1 to see the references).

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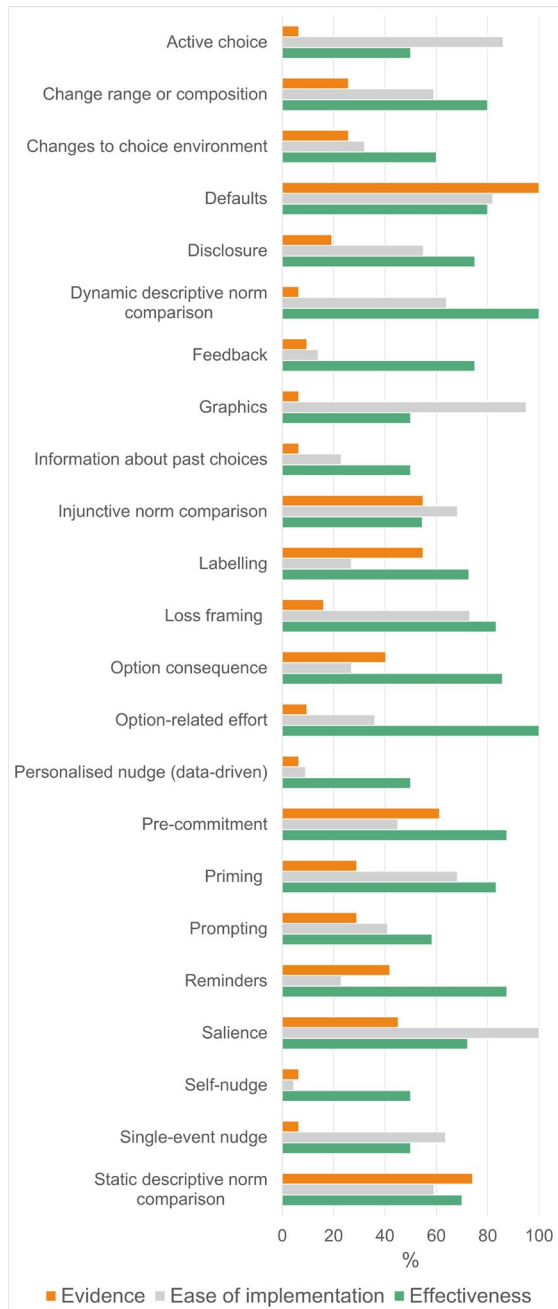
Figure 4. Evidence, ease of implementation, and effectiveness of nudges.

Nudging strategies and their relation to rebound effects

The relation is divided between nudges that are assumed to be most effective in preventing RE and nudges that could potentially lead to more RE (Figure 5). This relation creates the basis for the tool. The RE categories 'Moral licensing' and 'Motivational crowding' seem to be most

sensitive to nudging and their risk of leading to more RE. Further, it is evident that the nudge category 'Decision information' is assumed to be most effective in preventing RE. However, they are also the ones that could lead to more RE (especially the descriptive norm comparisons).

Prescriptive Study

The tool was developed to guide designers in the selection of appropriate nudges for tackling specific RE in the early phases of design. The tool consists of five key steps structured around eight Excel tabs (Figure 6). The tool can be accessed on the following link: https://doi.org/10.11583/DTU.28513289.v1
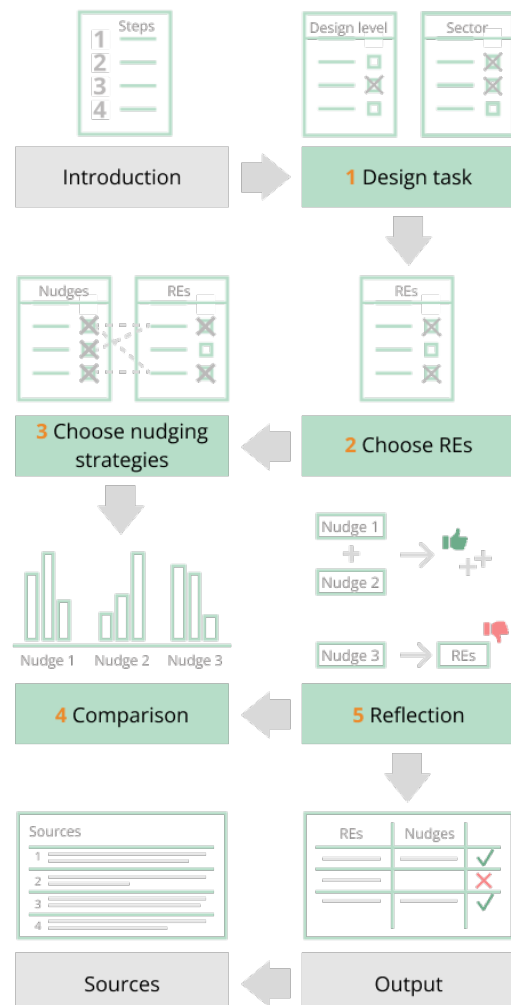

Figure 6. Steps in tool.

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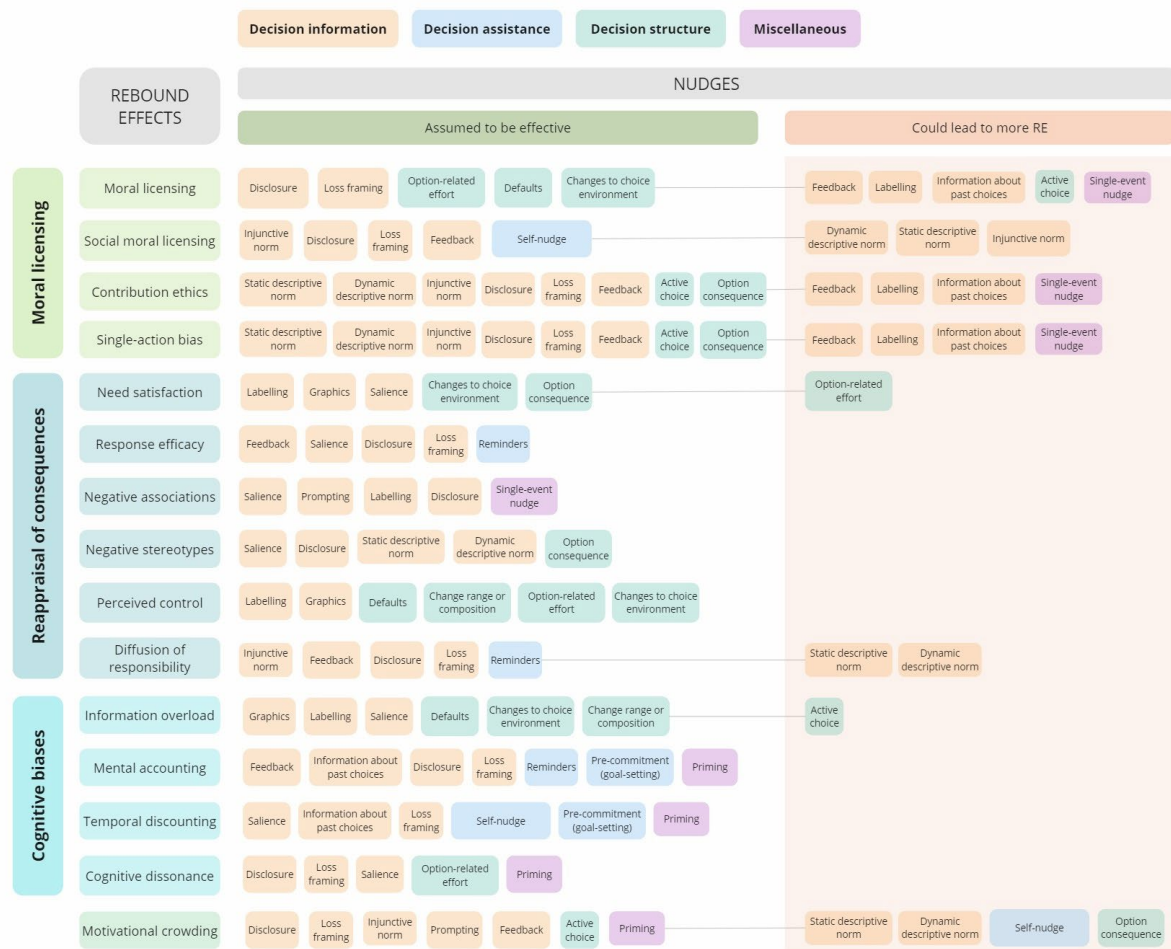
Figure 5. Relation between nudges and RE.

Descriptive Study II

The initial evaluation of the tool demonstrated a high usefulness and good potential for its use (Figure 7); "*It was nice to see that the nudges can be applied to more than one RE. This might also facilitate the design process*". To address the usability constraints faced by Excel, shifting to another platform or making the tool more automated might improve this in the future. Furthermore, it is important to note that the term 'rebound effects' remains difficult for non-experts to understand, as said by one of the design engineers "*there was a lot of terminology, which an unexperienced designer in this field might find confusing*".
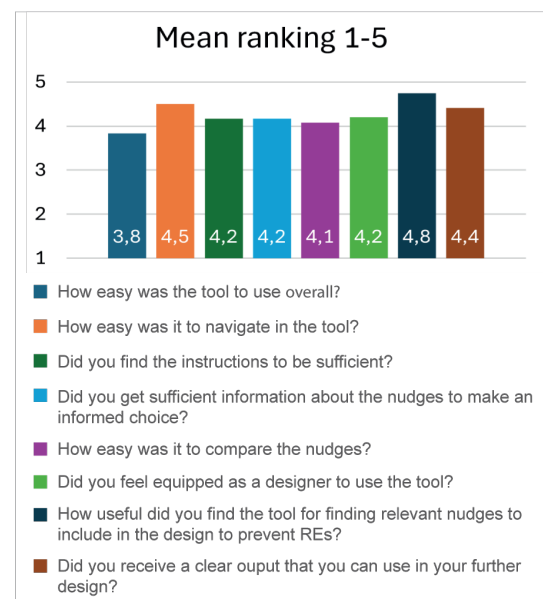

Figure 7. Survey results

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Discussion and future research

The results suggest that nudges within the category 'Decision information' have the biggest potential for preventing RE. However, they are also the ones that could lead to more RE. Designers should be aware of this potential dual effect when choosing nudges.

Furthermore, the lack of knowledge on how to use nudging in the design processes for products, PSS, and socio-technical systems is identified as an important gap. Research on rebound effects should further examine the link between 'design process' and nudging. This would also strengthen the usefulness of the presented tool as it could link nudging to specific design processes, especially looking at the early phases of design.

Reflecting on the underlying information of the effectiveness and ease of implementation of the nudges, it is important to note that deviations are expected depending on how the nudge is implemented, in what context, towards what target and by whom. This raises the question whether the effectiveness of nudging is greater than using monetary incentives or mandates. Future research could investigate comparing these different approaches to behaviour change.

Additionally, there remains great controversy on whether nudging is ethical in terms of changing behaviour (Siipi & Koi, 2022). Suggested by Schubert (2017), this risk could be addressed with basic transparency - which holds an opportunity to become a key component to implementing nudging in future research.

Finally, the categorisation of RE as well as their relation to nudges could be elaborated upon in future research, potentially expanding to rebound mechanisms within the field of economics. To evaluate the relations presented in this paper, an important next step is to test these connections and provide more insight into RE and nudging, as well as nudges leading to RE.

Conclusions

This study provides an overview of 23 nudges that could be used to counteract the behavioural rebound mechanisms to prevent RE. This relation is synthesised in a tool for designers to use in the early phases of design, thereby answering the research question: How to support designers to select nudging strategies to prevent RE in the early phases of design?'.

The identified nudges cover 'Decision information', 'Decision structure' and 'Decision assistance', and 'Miscellaneous'. Based on feedback sessions with various experts and designers using the tool, there is a clear indication that nudging can be an effective and easy implementable strategy to tackle RE.

Another key output is the design tool which shows great potential in aiding designers to prevent RE by suggesting nudges in the early phases of design. This tool adds value by being one of the first RE prevention tools with directly applicable strategies for products, product-service systems and socio-technical systems. In summary, this study aims to inspire as well as support researchers and designers reaching the full potential of sustainable design by preventing RE

Acknowledgments

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