Research paper
6th PLATE 2025 Conference
Aalborg, Denmark, 2-4 July 2025

Leverage Points as an Analytical Framework for Preventing Rebound Effects: An Exploratory Study

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Keywords: Rebound Effects; Design Thinking; Systems Thinking; Leverage points; Systemic Design.

Abstract
Despite global efforts toward sustainability, greenhouse gas emissions continue to rise, partly due to rebound effects (RE), i.e., systemic responses that offset the potential sustainability benefits of sustainability interventions. Designers often struggle to prevent RE due to dynamic complexities characterized by non-linearity, feedback loops, and delays. This paper explores how systems thinking, specifically the Leverage Points Framework (LPF), can support design activities in ideating and designing strategies for preventing RE. Through an exploratory case study of an electric car-sharing system, LPF and ideation techniques were applied to devise potential design strategies to prevent RE emerging from five identified RE mechanisms. Our findings suggest that integrating leverage points into the design process encourages a more systemic and comprehensive approach to ideation, expanding design opportunities towards the prevention of RE. We conclude that combining systems thinking with design thinking enhances the potential for creating effective, sustainable interventions and recommend further research to evaluate the practical potential of the proposed framework.

Introduction
Despite global efforts towards sustainability, the total Greenhouse Gases (GHG) emissions continue to rise (UNEP, 2021). The gap between sustainability-oriented actions and the expected reduction in resource use (such as energy and material) is partially explained by the so-called Rebound Effects (RE). RE refers to systemic responses that partially or entirely offset the potential sustainability gains of interventions (Guzzo et al., 2023).

Although RE are widely recognized, fundamental scientific gaps hinder their prevention (Andrew & Pigosso, 2024; Hertwich, 2005). The few studies that offer recommendations to address RE (Reimers et al., 2021) are focused on policy interventions (Azevedo, 2014; Colmenares et al., 2019; Greening et al., n.d.). Additionally, much attention has been given to the effects of RE, while the mechanisms necessary for addressing them remain underexplored (Guzzo et al., 2024; Lange et al., 2021).

Addressing RE requires diving into the dynamic complexities emerging from the nonlinearity, feedback loops, delays, and accumulations inherent of socio-technical systems (Guzzo et al., 2023). Designers often grapple with the dynamic complexities of systems, which leads to a trial-and-error approach for developing and testing design interventions (Scoones, 2007). Often, poor understanding of these dynamic complexities, especially feedback loops and delays, leads to negative consequences that off-set or backfire the initial intentions of the design intervention (de Gooyert et al., 2016; Guzzo et al., 2023). Thus, there is a need for a systemic perspective and toolkit towards understanding the complexity of the designed system towards the prevention of RE (Madlener & Turner, n.d., Oliveira et al., 2024).

By adopting a systemic understanding of social and technical contexts, designers can enhance the effectiveness of their interventions by hedging against or leveraging on higher-order effects (such as RE (Dori et al., 2020))), generated by the interplay of feedback loops (Oliveira et al., 2024).

The Leverage Points Framework (LPF) offers a promising approach for addressing RE by helping to identify intervention variables and supporting system change by showing how small shifts in one point can lead to significant impacts in the system (Meadows, 1999). While LPF has been used to address sustainability challenges (Kieft et al., 2020), it has not yet been applied to RE.

This paper investigates how systems thinking and the concept of leverage points can support design activities in devising design strategies capable of preventing rebound effects.

Theoretical Background

This section elaborates on two key elements for this study: rebound mechanisms and the Leverage Points Framework (LPF).

Rebound Mechanisms

Causal frameworks for explaining RE via rebound mechanisms are on the rise (Castro et al., 2022; Metic & Pigosso, 2022). Rebound mechanisms refer to the causal pathways (i.e., cause and effect relationships) mediating a given system intervention and the RE (Lange et al., 2021). System interventions will activate rebound mechanisms via the interplay of variables that causally determine its existence and moderated by contextual parameters, resulting in a RE of a given magnitude (Guzzo et al., 2024). To capture the systemic nature of rebound mechanisms, Guzzo et al. (2024) developed a (non-exhaustive) generalizable catalogue of rebound mechanisms utilizing causal-loop diagrams (CLDs). CLDs capture causal relations between variables operating in the system while emphasizing feedback loops and delays.

Figure 1 illustrates a generic rebound mechanism, agnostic of any specific intervention. Starting in the top variable: sustainability actions aiming at reducing local resource consumption at the local level, such as increasing efficiency of consumption or production, may activate a rebound mechanism (by triggering a certain variable that explains consumption or production activities), leading to responses in the social system that increase demand for products and or services. The change in supply or demand is depicted in arrows, *Links in red depict opposite relations (minus sign "-") and green ones represent variables increasing at the same direction (plus sign "+").*

Structural analysis of the rebound mechanisms enables identifying ways to prevent or mitigate RE, identifying leverage points that weaken the

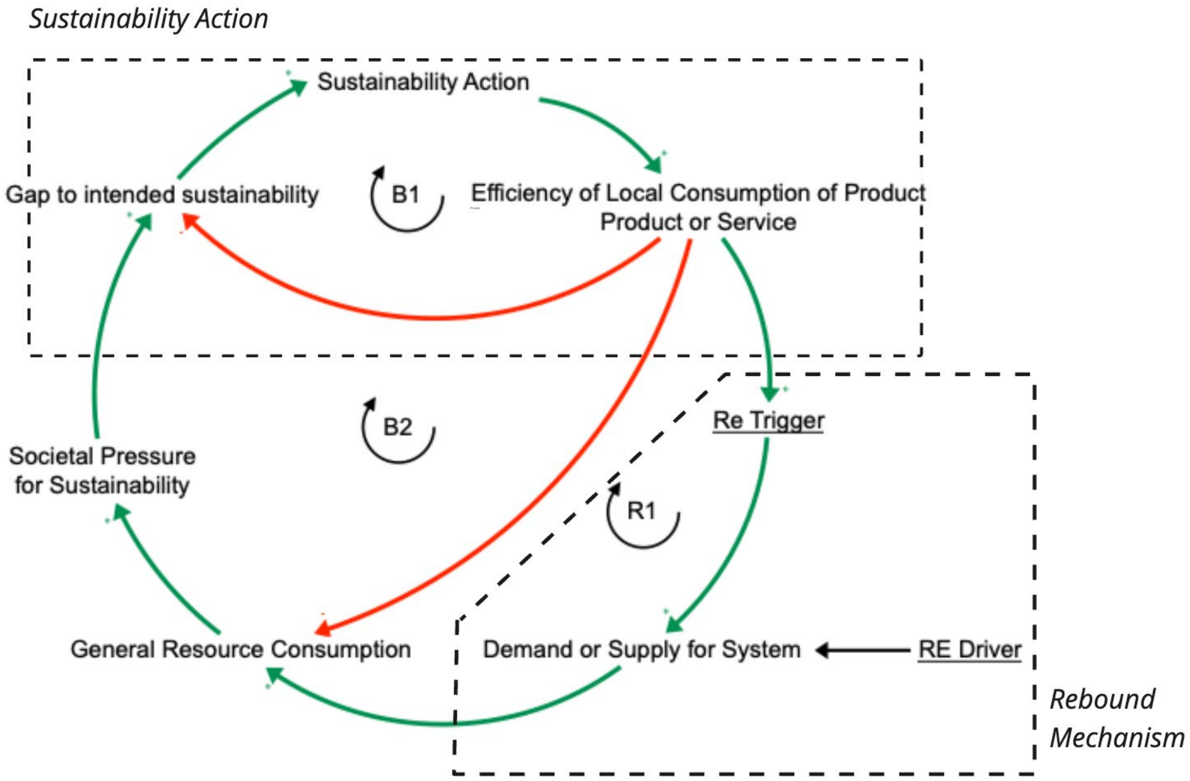

Figure 1 – Generic Rebound Mechanism adapted from (Guzzo et al., 2024).

effects of triggers, drivers, and feedback loops sustaining the rebound mechanisms (Guzzo 2024).

Leverage Points Framework (LPF)

LPF is an analytical framework capable of supporting decision-makers in addressing systemic, dynamic, and complex problems. Meadows postulates a hierarchy of 12 leverage points (LP) of intervention, with increasingly transformative potential in the system (Figure 2). LP is defined as *"places within a complex system where a small change can produce large shifts in the system's behavior"* (Meadows, 1999).

LPs can be arranged into four groups of interventions (Abson et al., 2017):

I. **Parameters**: refer to tangible – often physical – aspects of the system: taxes, prices, sizes of stocks (system accumulations), or rates of change. Intervening at this level is relatively straightforward, but not particularly impactful in driving systemic change. In a car-sharing system, for instance, changes in parameters might be related to the price charged per use (LP 12) or the fleet size of vehicles (LP 11), or setting-up processes for repairing the vehicles (LP 10).

II. **Feedback**: refers to how the information circulates within the system (through processes) and feedback into itself. Intervening on feedback involves, for example, changing the time required to process and deliver a vehicle to a customer (LP 9), decision rules for controlling the fleet size within inventory management (LP 8), or the extent to which profits are reinvested to expand business activities (LP 7).

III. **System structure:** Effectively change how information is shared, as well as those who have access to information (e.g., by adding new processes, accumulations or buffers). Examples of additional system structures in a car sharing system could be enabling users to have live access to fleet availability or monitor the environmental impact induced by their use (LP 6), incentives and punishments rewarding desired behaviors (LP 5), and the power for customers collectively decide the incentives for their behaviors (LP 4).

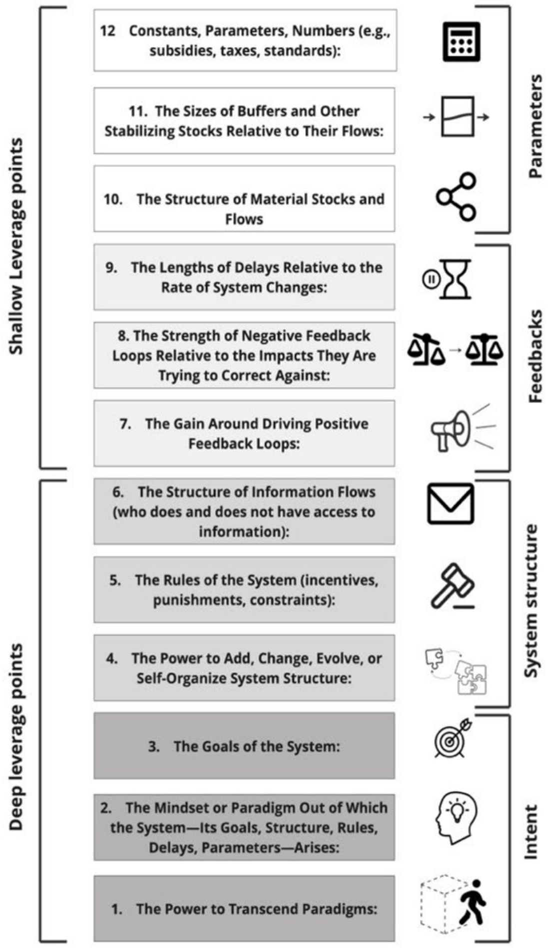

Figure 2 - The Leverage Points framework

IV. **Intent**: refers to the worldview, underlying values, and paradigm in which actors behave within the system, operate, and make decisions. It is the most intangible and difficult-to-change aspect of a system, yet the most determinant of system behavior. Changing the intent of a mobility platform could mean moving from profit maximization towards ensuring sustainable, efficient and effective mobility.

It is important to note that leverage points are at different hierarchical levels and are inherently linked to one another. Shallower interventions contribute to deeper transformations over time, and vice-versa.

Method

The research question guiding this study is: "*How could designers use leverage points in ideation sessions to systematically devise design strategies capable of preventing rebound effects?*".

The main hypothesis is that LP can enhance systems thinking in design by helping to identify ways to tackle RE. LPs are seen as critical elements within a complex system that, when identified, enable designers to implement interventions leading to significant and positive changes in system behavior.
To explore the use of LPF in devising design strategies that can support the prevention of RE, this study uses an inductive approach departing from one specific case towards broader generalizations of the findings in five research steps (Figure 3). The case focuses on a retrospective analysis of an electric car-sharing product-service system (PSS) which is subjected to RE.

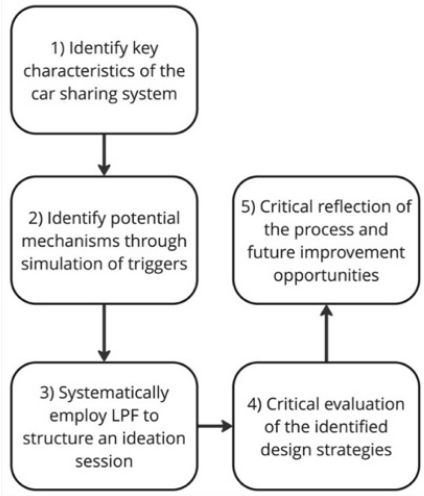

Figure 3: Process overview

Step 1: Identify key characteristics of the car-sharing system
Transitioning to electric vehicles and shifting to shared mobility is seen as an alternative to reduce the negative environmental impacts of mobility, including emissions and resource consumption. However, without careful design, these solutions can inadvertently lead to RE, such as increased overall travel demand or vehicle production – displaying the complexity of the system. The selected car-sharing PSS is GoMore, a Danish company offering three value propositions: leasing, ridesharing, and peer-to-peer car rental services. Our analysis emphasized the intended sustainability gains and induced impacts of GoMore's value propositions in comparison to traditional private-owned mobility. The data was collected from the company's website (www.gomore.dk) and supplemented by the available literature.

Step 2: Identify and select mechanisms through the stimulation of triggers
Departing from the key characteristics of GoMore's value propositions, we systematically examined the extent to which these offerings could activate the rebound mechanisms systematized by Guzzo et al. (2024). For instance, a mobility PSS reduces the cost of consumption of private mobility, leading to a release in the budget for additional consumption. If users re-spend the budget in resource-intensive activities, a RE in total resource consumption would be observed (Guzzo et al., 2024). This process resulted in the identification of five potential rebound mechanisms stimulated by the PSS platform. CLDs representing the identified mechanisms were used to visualize the causal pathway linking triggers, drivers, and potential rebound effects on resource consumption.

Step 3: Systematically employ LPF to structure an ideation session
Based on the results of Step 2, we proceeded to identify actionable elements of the rebound mechanisms that could be influenced through design, at different leverage points. The ideation process started by addressing shallow leverage points (such as parameters, numbers, and numbers) and later deeper leverage points (such as transcending paradigms). As a result, the ideation process resulted on the consolidation of several design strategies that could support in the prevention of rebound effects.

Step 4: Critical evaluation of the identified design strategies
The ideated design strategies were critically evaluated regarding three main criteria: (1) feasibility of implementation; (2) effectiveness to address potential RE; (3) "designability" (i.e., the extent to which the intervention is within designer's decision space).

Step 5: Critical reflection of the process and future improvement opportunities
The final step was to reflect upon the overall process and the use of leverage points to link systems thinking and design thinking for the prevention of rebound effects. This reflection key findings contributed to the generalization of the results obtained in this study. These insights are presented in section 5. Discussion.

Results

This section presents the key findings of research step 1-4.

Step 1: Key characteristics of the car-sharing system

GoMore is a Danish mobility platform that integrates peer-to-peer car rental and ridesharing and provides vehicle leasing contracts. In peer-to-peer modes, customers act as clients on the platform, offering either their vehicles for rent or posting pre-scheduled rides to be shared. Leased vehicles are directly provided by GoMore, who retain their ownership throughout the contract.

Rebound mechanism	LP	Design strategy	Evaluation		
			Feasibility	Effectiveness	Designability
Re-spending Mechanism	12 (I. Parameters)	Enhance product efficiency as a means to counteract additional consumption originating from past REs.	High: Implementation is straightforward.	Low: May strengthen existing rebound effects reliant on product efficiency.	High: Controllable within design parameters.
Income Mechanism	8 (II. Feedback)	Strengthen Price feedback by setting limits on total mileage per trip or per user to reduce overuse, prevent long-distance travel, and encourage intentional use.	Moderate: Requires local adaptation and enforcement. From a business standpoint might not be viable due to market competition.	Moderate: Targets specific behaviors effectively in urban areas.	High: Easily designed.
Motivational consumption	6 (III. System Structure)	Inclusion of new information flows (e.g., estimating emissions for each trip before bookings as well as summaries of usage patterns), and allowing users to set personal sustainability goals.	Moderate: Relies on integrating novel technology for data collection and display.	High: Influences user behavior significantly by promoting awareness.	Moderate: requires collaborations with technical professionals and data providers.
Substitution effect	2 (IV. Intent)	From discussing the design of mobility system to discussing the design of human settlements & urban centers	Low: Complex and long-term process involving multiple stakeholders.	Very High: Addresses systemic causes of rebound effects at the root.	Low: Beyond the typical scope of design; requires interdisciplinary collaboration.

Table 1: Examples of different leverage points, corresponding design strategies and evaluation of strategies.

Participation in peer-to-peer services as a lessor is incentivized.
Through its propositions, GoMore intends to combine increased customer value to reduce the environmental impact of private mobility. Offering product-as-a-service reduces the cost of ownership and increases convenience and flexibility while optimizing efficiency and effectiveness through higher utilization rates and reduced idleness.

Step 2: Identified and selected mechanisms through stimulation of triggers

By linking the outcomes of the company's value proposition and evaluating the extent to which they stimulate rebound triggers, we were able to identify five relevant rebound mechanisms: (1) income, (2) re-spending, (3) substitution (4) motivational, (5) consumption time, and (6) moral hazard. The sixth mechanism, not present in the catalogue was supplemented through the literature (Ackermann & Tunn, 2024)
Reduced costs of consumption may activate three mechanisms simultaneously: (1) income mechanism occurs when savings due to the reduced cost of transportation are reinvested into more driving of the consumer's initial choice, while (2) Re-spending mechanism occurs when released budget is reinvested in additional consumption elsewhere. Lastly, (3) Substitution occurs when consumers change their consumption choice to a less resource effective choice in respect to a change in cost of consumption. (4) Motivational consumption mechanism happens when users perceive a product or service as a sustainable alternative, leading to increased consumption (5) Consumption time mechanism is triggered by easiness of consumption. For instance, enabling users move faster and easier from A to B through a sharing platform might lead to driving more and further.

Step 3: Results of systematically employing LPF to structure an ideation session.

In total, our ideation session resulted in 68 unique potential design strategies that could prevent the occurrence of rebound effects, targeting at different leverage points with varying degrees of effectiveness. The ideas were widely distributed across the LP. Shallow LPs included 22 ideas from Parameters, often focusing on altering physical system parameters, and 11 ideas from Feedback, mainly eco-feedback. Deeper LPs included 23 ideas from System Structure, emphasizing co-creation with stakeholders, and 12 from Intent, targeting attitude and paradigm shifts.

Table 1 exemplifies the types of results achieved during the ideation process. The table contains strategies for 4 Rebound mechanisms and a critical evaluation based on the parameters set in the methods section.

Figure 4 deepens the example illustrating the income mechanism by representing the design intervention in CLD format. The figure displays how an intervention (LP5) could limit consumption by adding a feedback loop in the system regulating consumption per user. The introduction of dynamic price creates a balancing loop (B3) that limits the strength of (R1) that results in the RE.

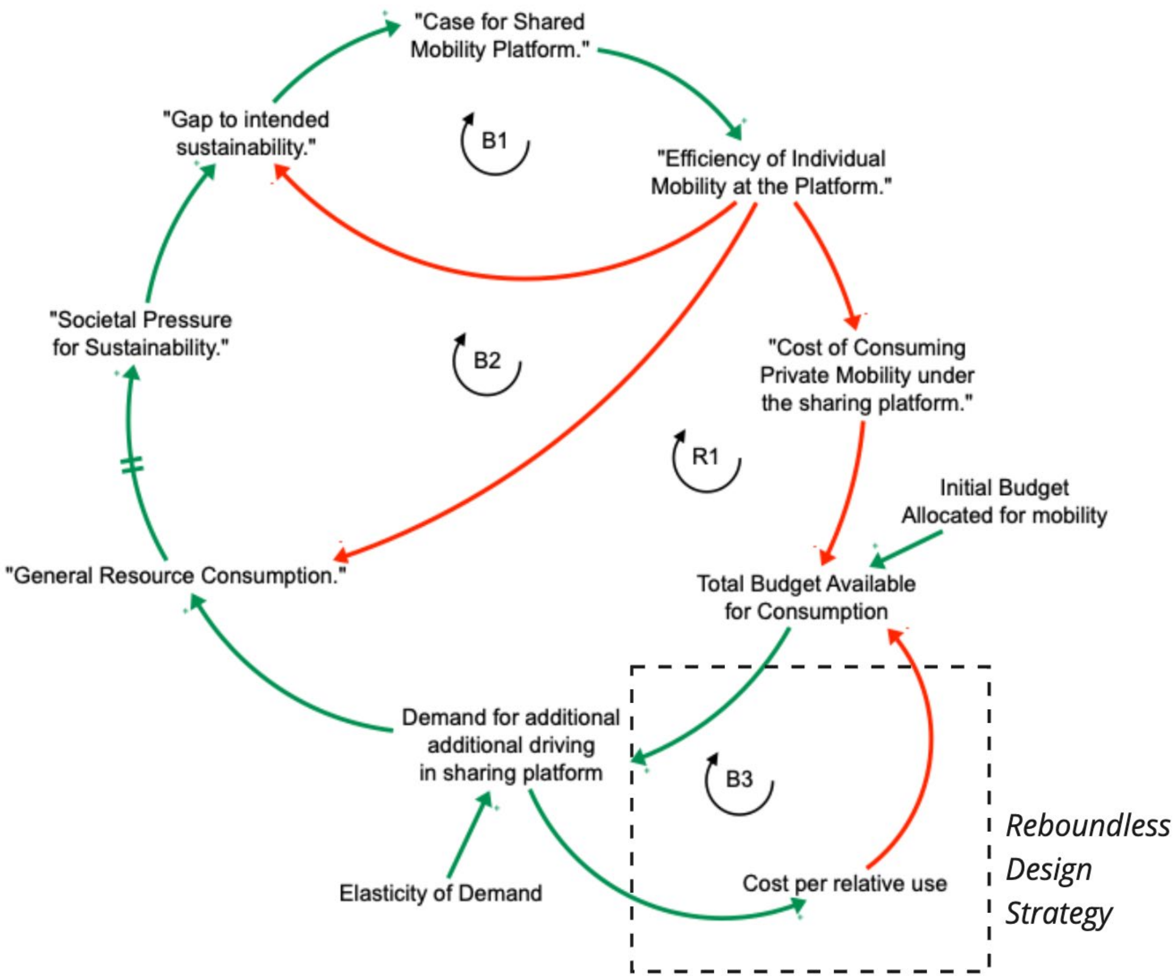

Figure 4. Income mechanism supplemented by an example of reboundless design strategy implementation (LP5) (Guzzo et al., 2024).

Step 4: Critical evaluation of design strategies

Several types of design strategies targeted at the product-, PSS-, and socio-technical system- levels were devised, providing multiple angles to engage with various leverage points. An example of a strategy was the inclusion of new information flows, e.g. estimating emissions for each trip before booking, as well as summaries of usage patterns.

The strategies were evaluated based on the three criteria earlier established (*Feasibility, Effectiveness and Designability*) and is illustrates in Table 1. The table illustrates a trade-off in design strategies: those targeting shallow leverage points, such as parameters and feedback, demonstrate high feasibility and designability due to their straightforward implementation and control within design parameters but exhibit lower effectiveness in addressing RE. Conversely, strategies aimed at deeper leverage points, such as system structures or intent, are more effective in mitigating systemic rebound effects but face challenges in feasibility and designability, requiring long-term, interdisciplinary collaboration and broader systemic changes. This highlights the balance needed between ease of implementation and impact.

The findings also suggest a relationship between the level of design intervention, the depth of leverage points addressed, and the designability between leverage points and design levels. Product-level strategies target shallower leverage points, like buffer sizes (e.g., limiting cars in transit-rich areas), while PSS and STS address deeper points, such as information flows (e.g., feedback before booking), linking intervention levels to leverage depth and designability.

Discussion

LP can guide designers to focus on control variables (aspects that can be manipulated), directing ideation toward interventions that shift the system in a desired direction towards target variables (the aspects we aim to change).

LPF offers a heuristic for identifying leverage points. The systematic analysis of their feasibility, effectiveness and designability helps determine the most points with most potential, nevertheless estimating the effects of the devised strategies to prevent RE proved complex (i.e., some identified strategies were prone to generate additional RE). Addressing this requires two key considerations:

I. Identifying the most impactful design strategies.

Strategies must be assessed for their potential to create meaningful change, which can be achieved through qualitative or quantitative model analysis. Qualitative methods, such as analyzing cause-and-effect relationships using CLDs allow designers to mentally estimate the outcome of design interventions in the system amid feedback loops. For example, the introduction of dynamic pricing would likely be more effective than a linear decrease on price as it weakens the feedback loop sustaining the income mechanism. Quantitative methods, including simulation-aided model analysis, offer deeper insights into determining the magnitude of potential RE (Metic 2024) and also on hidden leverage points and relative strength of feedback loops (Schoenberg et al., 2020). These approaches can support designers by unveiling counterintuitive system behavior, that may pose trade-offs between variables and REs – often arising from system complexity and dynamism.

II. Assessing the Scope and “Designability” of Strategies

Some strategies extended beyond design’s immediate influence, requiring policy-level interventions, or raised questions about their “designability.” Evaluating strategies across various levels clarifies where design influence is most actionable and where collaboration with policymakers may be necessary. For influencing rebound mechanisms, triggers and drivers were identified as the most actionable elements within a designer’s scope.

Lastly, further integrating LP into design processes requires moving further from heuristics to better defined filtering and prioritizing criteria and processes. In that sense, there is space for clearer directions for the applicability of the LPF for RE prevention by attributing existing mitigation strategies to the different leverage point levels. Also, the feasibility, effectiveness and designability analysis can benefit from further reasoning guidance.

Despite the challenges, incorporating LP into the design process proved beneficial. It encouraged a more systemic approach to ideation, expanding the range of design opportunities beyond superficial and simplistic solutions. The diverse strategies highlighted the richness of ideas possible when using systems thinking.

Through an analysis of process reflections, a future process framework is proposed for more effectively integrating LP as an ideation tool in design to address rebound effects (Figure 5). The proposed process framework builds upon the five steps sustaining this research by integrating 3 extra steps: identification of most impactful LP through mental or formal simulation (steps 3 and 4), approaches to assessing and filtering design strategies (steps 6 and 7), and testing the effect of the selected strategies (step 8), indicated by the stippled lines.

Future Research

Rather than using the case study as a reference, future research could focus on mapping the rebound effects associated with the company's service and analyzing the creative process and key considerations that shaped its specific characteristics. Furthermore, the design strategies must be implemented and monitored over time to see whether they are really preventing or to what extent they are preventing the rebound effects from happening.

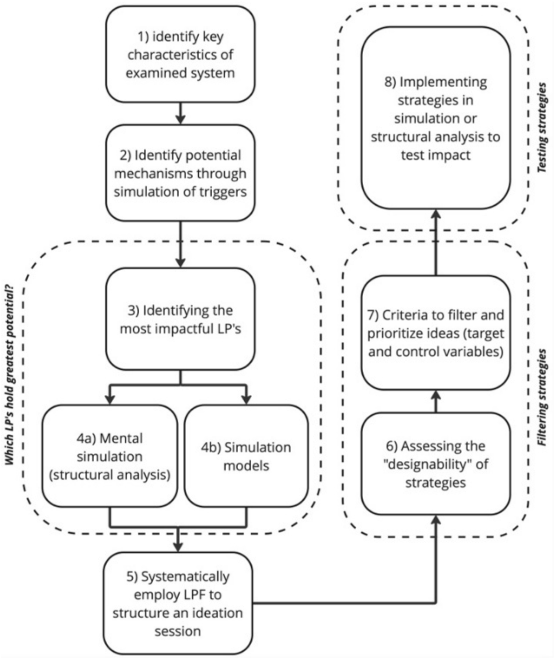

Figure 5: Proposed future process overview for the integration of the leverage points in design for the prevention of rebound effects

Final Remarks

Through an inductive case study of a car sharing system, this paper demonstrated the systematic use of LP (from parameters to deeper systemic paradigms) in design to expanding the range of design strategies for preventing RE beyond immediate and surface-level solutions. Therefore, our contribution to rebound effect prevention focuses on *ex-ante* measures—intervening during the design process, before products or systems are implemented in the market—to address potential rebound effects at their root.

While this approach generated a diverse and insightful set of ideas, the evaluation of their practical potential and "designability" remains an area for future research, as well as the evaluation of their potential to prevent rebound effects.

To support future research, a 10-step approach is proposed for the systematic integration of leverage points in the design process for the prevention of potential rebound effects.

Acknowledgments

Funded by the European Union (ERC, REBOUNDLESS, 101043931). Views and opinions expressed are, however, those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Council. Neither the European Union nor the granting authority can be held responsible for them.

We acknowledge the use of AI during the writing process of this paper and the ideation of reboundless design strategies.

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