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Exciting and profitable sustainability through Sufficiency Engineering

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*Institute of Product Engineering, Saarland University, Campus E2 9, 66123 Saarbrücken, Germany** Corresponding author. Tel.: +49 (0) 681-302-71234; fax: +49 (0) 681-302-71317. E-mail address: kristian.koenig@uni-saarland.de**Abstract**

In view of the three sustainability strategies (efficiency, consistency, and sufficiency), sufficiency is often attributed to be the least exciting one – leading to challenges in societal acceptance – and is seen not economically viable through its focus on reduction in today’s consumption-driven economy. Against this background, the present work promotes a different perspective on this traditional understanding. By employing the Kano Model of customer satisfaction, the concept of ‘Sufficiency Engineering’ is introduced as a strategy to effectively link excitement and profitability in sustainable development, thereby fostering a long-term customer relationship.

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Keywords: Sufficiency; sustainability; product development; sufficiency engineering**1. Introduction**

The overuse of Earth’s finite resources has emerged as one of the most pressing challenges to sustainable human development, particularly in industrialized nations where consumption patterns far exceed ecological limits (in particular, the planetary boundaries [1]). As the global community grapples with the implications of unsustainable growth, critical thinkers have increasingly called for systemic changes in how we produce and consume goods [2]. In this context, the concept of a sufficiency economy [3] has garnered attention as a potential pathway towards a more sustainable behavior in society. However, the discourse surrounding sufficiency is often characterized by terminologies such as “less”, “enough”, “accept”, “reduce”, or “refuse”, which can be perceived as restrictive or even counterproductive to customer excitement. Thereby, we define excitement requirements or attributes of a product accordingly to Kano et al. [4] as unexpected features or qualities that delight customers and create high satisfaction even if they were not initially anticipated. Therefore, customer excitement generates a strong, positive emotional response from customers when a product exceeds their expectations.

This yields our research question: *How can sufficient products be designed to generate environmental benefits and simultaneously enhance customer excitement?*

To answer this question, the present work explores how products can be aligned with sufficiency principles to appeal to consumers, thereby facilitating the widespread adoption of sustainable behaviors. Specifically, the research focuses on understanding how product design can evoke positive consumer experiences while encouraging a reduction in resource-intensive consumption.

To elaborate on this topic, in Section 2 fundamentals on the sufficiency concept in products and traditional consumption patterns are presented. In Section 3, a synthesis into positive perspectives on sufficiency through product design by ‘Sufficiency Engineering’ is proposed. Thereby, the well-known Kano Model [4] of customer satisfaction is used, which explores how sufficiency can be integrated into products. An economic perspective on the potential impact of these shifts on both product landscapes and business strategies is also discussed. Finally, Section 5 concludes with a summary of key insights and an outlook on future directions for research and practical implementation.

2. Fundamentals

2.1. Strategies for Design for Sustainability

Design for sustainability emphasizes environmental responsibility and social stewardship, aiming to minimize negative impacts on the Earth's planetary boundaries while delivering customer value. The concept is often operationalized through the triple bottom line, conscientiously balancing the environmental, social, and economic pillars of sustainability [5]. However, a significant challenge arises when economic growth is used as a trade-off for environmental or social expenses [6]. Therefore, Hauschild and colleagues proposed to reorient on the environmental dimension of sustainability promoting the original focus of life cycle engineering [7]. Three core sustainability strategies attempt to reduce environmental impacts in different ways [8], as visualized in Fig. 1:

- (Eco-)Efficiency is about optimizing the overall resource use to maintain or improve product quality, enhancing energy efficiency, reducing materials, and streamlining production, though it is bound by technological limits.
- Consistency (or eco-effectiveness) mainly intends environmentally compatible technologies that harness the materials and services of ecosystems without causing their destruction [9] (such as circular economy in aiming to establish closed-loop systems [10]). Key approaches include design for disassembly, reverse logistics, and supplier partnerships for material recovery, resulting in an altered and reduced environmental footprint.
- The sufficiency strategy shifts focus on essential needs, reducing consumption by minimizing material and energy inputs. This approach promotes durable, modular products and encourages models like sharing or leasing, reducing environmental impact by emphasizing long-term utility and minimalism. The environmental impact is minimized by addressing only the essential needs through the product, while avoiding unnecessary environmental impacts caused by non-essential need fulfillment.

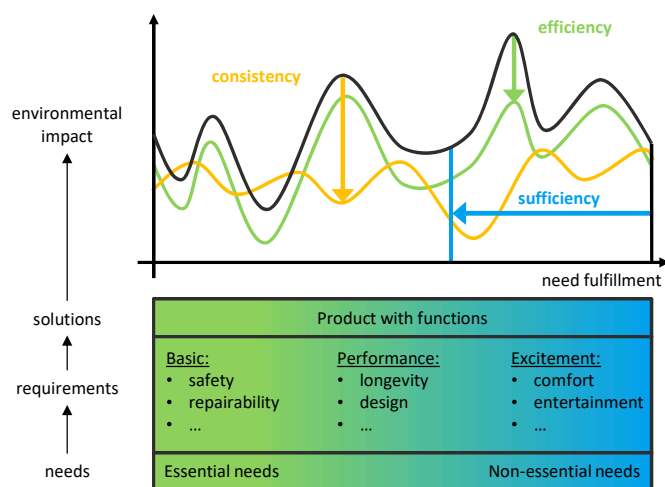


Fig. 1. Sustainability strategies reducing environmental impacts in relation to customer needs.

2.2. The Kano Model of Customer Satisfaction

A central aspect of sustainability considerations is to focus on functionalities or provided value (such as the principle 'functional unit' in life cycle assessment), when evaluating a product's environmental impacts. Thus, establishing a customer-centric approach to product development enables organizations to deeply understand customer needs on the one hand, and to assess the environmental effects of their services on the other hand. This helps them to create products that resonate with their target audience, foster loyalty, and are environmentally friendly. One method to support the operationalization of catching the voice of customer, is the Kano Model developed by Kano et al. in 1984 [4]. It classifies customer requirements by their impact on satisfaction, identifying an exponential relationship between need fulfillment and customer excitement. Requirements are divided into three main categories:

- Basic requirements are fundamental features customers expect by default. Their absence causes dissatisfaction, but their presence only adds minimal satisfaction.
- Performance requirements represent features where increased fulfillment directly boosts satisfaction. These requirements are 'one-dimensional' [11], as satisfaction scales with performance.
- Excitement requirements are unexpected features that delight customers, significantly increasing satisfaction when present, but not causing dissatisfaction if absent.

Products meeting only basic and performance requirements are viewed as average and interchangeable. The Kano Model thus reveals purchase drivers, with excitement requirements strongly influencing decisions, while one-dimensionals add value if outstandingly placed within the model's framework.

Expanding on Kano's original model, newer classifications highlight inverse quality attributes, where reducing or limiting certain features can actually enhance satisfaction [12]. Additionally, indifferent attributes – features that neither increase nor decrease satisfaction – are also critical for resource efficiency, though their relevance can vary by market segment. This nuanced view suggests that beyond mere enhancement, customer satisfaction can also benefit from strategic feature reduction and careful resource allocation in development.

2.3. Sustainability Strategies in the Kano Model

As demonstrated in [13], the Kano Model can be used to evaluate and analyze sustainability measures from the customer's perspective. Based on such considerations, in an earlier work [14] the sustainability strategies – efficiency, consistency, and sufficiency – have been integrated into the Kano Model of customer satisfaction from a generic point of view and based on the traditional understanding discussed. As illustrated in Fig. 2, the effect of product changes in each of the three sustainability strategies is mapped on customer satisfaction, while it can be concluded:

- Within the Kano Model, efficiency improvements shift quality attributes along the performance axis, towards increasing customer satisfaction. For example, reducing a vehicle's energy consumption without compromising

functionality reflects an efficiency gain, positioning it favorably on the performance scale.

- Consistency ensures a reliable fulfillment of customer expectations, focusing on aligning product design with natural principles without necessarily enhancing performance. In the Kano Model, consistency influences customer satisfaction vertically, indicating changes in requirement fulfillment, such as designing products for easier disassembly or material recovery, can evoke enhanced or reduced satisfaction.
- Sufficiency shifts focus from maximizing satisfaction to achieving essential functionality with minimal resources. In a classical understanding, sufficiency-driven changes generally lower need fulfillment and satisfaction within the Kano Model. For instance, simplified products with only essential features (e.g., omitting car air conditioning) align with sufficiency strategies, reducing the level of (non-essential) need fulfillment.

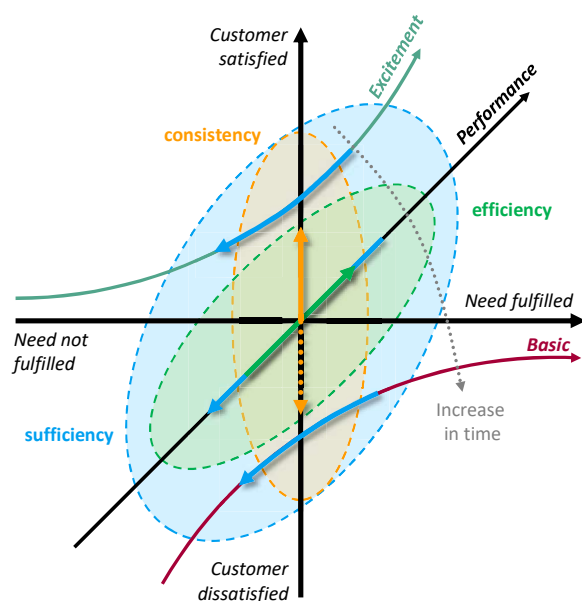


Fig. 2. Traditional understanding of the sustainable design strategies in the Kano Model of customer satisfaction [14].

While efficiency measures positively affect customer satisfaction in the Kano Model and are thus easier for product developers to justify, sufficiency is typically associated with lower satisfaction due to reduced functionality. This can make sufficiency-oriented products appear less attractive, reinforcing the perception that sustainable products limit customer expectations. However, in contrast to the implementation of efficiency strategies, sufficiently designed products face less of the challenge of triggering the rebound (or backfire) effect, which can negate the benefits of efficiency improvements by increasing consumption [15]. Consequently, achieving a balance between sustainability and customer satisfaction requires a reframing of sufficiency strategies.

3. A Positive Perspective on Sufficiency

3.1. Customer Satisfying Sufficiency

In general, sufficiency can be also satisfying as it aligns product development with the growing societal demand for sustainable and mindful consumption. As highlighted by Bocken and Short [16], there is a shift towards focusing on essential needs rather than promoted wants emerging in product development. This movement has gained traction as consumers increasingly seek products that fulfill their essential needs while minimizing unnecessary overconsumption and, as a consequence, environmental impacts. In this context, sufficiency represents an opportunity to reshape industries and challenge conventional notions of consumerism.

The excitement around sufficiency can traditionally be understood through the lens of minimalism, a concept that promotes intentionality and mindfulness in consumer behavior. Research indicates that minimalism is not only beneficial for environmental sustainability but also enhances individual well-being. Studies [17,18] show that minimalist lifestyles foster self-awareness, reduce stress, and promote positive emotions, as well as better quality of life. By prioritizing functionality over excess, sufficiency encourages consumers to focus on what truly adds value to their lives, rather than being driven by fleeting desires or societal pressures.

This approach fosters excitement because it resonates with a growing desire for simplicity and purpose in an increasingly complex world. In a consumer culture dominated by excess, sufficiency offers an alternative that feels both refreshing and rewarding. Rather than seeing sufficiency as restrictive, it can be viewed as liberating – offering consumers the freedom to make choices that align with their values, health, and the planet.

From a business perspective, minimalism offers new opportunities for product innovation and value creation [19]. By designing products that meet essential needs with minimal environmental impact, companies can tap into a growing market of eco-conscious consumers. This shift not only reduces the environmental footprint but also creates long-term value by fostering deep customer loyalty.

However, one main challenge lies in reframing the narrative surrounding sufficiency. There are already existing several attempts to rename the strategic principle sufficiency, such as through “need substitution” [20] to shed its restrictive undertone carried with terms like “reduce”, “refuse” or “enough” implying limitations. To generate excitement, the focus must shift towards the positive aspects of sufficiency-emphasizing how these products contribute to a healthier, more sustainable future and promote more transparently the benefits for customers and the environment. This can be achieved through better communication and by showcasing the benefits of sufficiency in a way that resonates with consumers’ desires for authenticity, quality, and environmental responsibility.

3.2. Sufficient Product Design

For implementing the sufficiency strategy in products and society, design – and consequently, product development – plays the pivotal role [21]. The way products are designed

directly influences both the consumer's decision to purchase a more environmentally friendly product (sustainable consumption) and the way products are later used (sustainable behavior). Table 1, developed by the authors based on a review of existing approaches to sustainable product development with a specific focus on sufficiency strategies, provides a deep look into sufficient product properties (SPPs) that can be shaped through product design, the associated product system or through an appropriate business model. Thereby, SPPs refer to product characteristics that enhance essential user needs such as quality, safety, functionality, durability, and resource efficiency while aligning with sufficiency principles by avoiding excessive consumption, unnecessary features or overproduction. If these SPPs are effectively incorporated into a product, the resulting design could be classified as a sufficient product design.

Fundamentally, the presented design aspects in Table 1 represent long-standing practices and established principles in product development. Nevertheless, products exhibit increasing variety and shortening life cycles [22] or an increasing material complexity [23]. Therefore, the objective of research in sufficiency must be to more clearly demonstrate the advantages for developers, decision-makers, and customers, thereby encouraging more frequent and robust integration of SPPs into products.

Table 1. Design strategies for implementing sufficiency in products and exemplarily sources (further strategies also conceivable).

Design strategy	SPP	Source
Address essential customer needs	Minimalistic Design	[24]
	Low complexity	[25]
	Safety and reliability	[26]
	...	
Design for extended product use	Product longevity	[27]
	Timeless design	[21,28]
	Modularity	[29]
	Repairability	[21]
	Emotional durable design	[30]
	...	
Material-oriented design	Establishment of sharing principles	[27]
	Recyclability	[31]
	Low material diversity	[32]
	Lightweight design	[8,33]
	...	
Promote environmental benefits	Establishment of local products	[34]
	Clear information on environmental footprint	[35]
	...	

4. Exciting and Profitable Sustainability through Sufficiency Engineering

The principle of 'Sufficiency Engineering' as a design paradigm is based on the deliberate implementation of SPPs in product development to enhance customer satisfaction. Fundamentally, Sufficiency Engineering does not address all

human needs, recognizing that intangible needs should not be satisfied through purchasable products in the context of sustainable consumption. Additionally, sufficiency practice naturally involves reducing desires to focus on essential needs, which can vary from person to person. The idea behind Sufficiency Engineering is that the fundamental needs met by material products and consumer goods are developed in such a way that they do not promote overconsumption but instead evoke satisfaction due to the product's functionality and quality.

4.1. Implementation of Sufficiency Engineering in Product Development

Based on the SPPs presented in Table 1, the authors have compiled at least four design strategies for implementing Sufficiency Engineering attributes into products, offering a proposal for their integration.

4.1.1. Address Essential Customer Needs

Approaches of implementing sufficiency in products must focus on user-centricity, functionality and minimalism. By involving customers in the design process, companies can tailor products to meet specific needs, fostering satisfaction and long-term engagement. Minimalistic design, a core element of sufficiency, eliminates unnecessary features while maximizing functionality, enhancing user experience and minimizing resource use. Widely adopted in consumerist countries like the USA, Japan, and European nations [36], minimalism serves as a paradigm shift, positioning products such as streamlined notepads or no-frills services as practical, sustainable solutions. Furthermore, safety is an essential requirement in product development, ensuring the fundamental needs of security and reliability for customers are met.

4.1.2. Design for Extended Product Use

There are numerous strategies to extend product lifespans. In general, as Cooper [37] has emphasized, product lifespans play a pivotal role in achieving sustainable consumption. Lifespans can be prolonged through enhanced durability, addressing issues like planned obsolescence and shifting consumer trends by prioritizing quality improvements and timeless aesthetics. Additionally, maintenance practices such as repair and refurbish further extend product usability [28]. Emotional durable design [30], which focuses on fostering long-term user attachment, is another critical aspect of Sufficiency Engineering. Fundamentally, the sufficiency strategy aims to ensure prolonged product usability through deliberate and sustainable product design, thereby ensuring customer excitement over a long time.

4.1.3. Material-Oriented Design

In sufficiency-driven material-oriented design, a primary goal is to reduce the overall consumption of raw materials. This can be accomplished by adopting strategies such as sharing principles, which effectively limit the total number of products required. Equally important is the careful selection of materials to ensure they promote extended product lifespans. By enhancing qualities like texture, aesthetics, and timeless

appeal, materials can foster emotional durability and sustained user engagement. Furthermore, this approach has the potential to spark excitement by creating products that are not only sustainable but also uniquely appealing through their thoughtful design. Overall, material selection and reduction hold a pivotal role in Sufficiency Engineering, emphasizing their significance in creating sustainable, enduring, and captivating product solutions.

4.1.4. Promote Environmental Benefits

Information about a product's environmental impact may influence purchasing decisions positively [22], enabling customers to make conscious choices for or against a product based on its environmental footprint. Within Sufficiency Engineering, the focus in this regard lies in emphasizing and promoting attributes such as regional sourcing or low environmental impacts as excitement factors, positioning them as key motivators to inspire and engage consumers.

4.2. Perspective on Business Cases and Economic Potential

Evaluating sustainability from an economic perspective remains a fundamental challenge. In this section we propose a perspective, focusing on sustainable development with economic continuity. This entails examining both the costs or investments required to enhance product sustainability and the potential revenue gains by the three sustainability strategies. It is very important to notice that in view of the Earth's biophysical limits, economic growth must not be used as a trade-off for environmental or social expenses as discussed by Kara et al. [6].

Considering the eco-efficiency strategy, it is generally expected to yield the lowest sustainability returns due to inherent limitations [38]. According to the Pareto Principle, further improvements would demand disproportionate investment, making the economic return questionable. Additionally, eco-efficiency measures may trigger a rebound effect, where the money spent on sustainable development drives sales but ultimately yields no net environmental benefit [15]. In the case of the consistency or eco-effectiveness strategy, the potential for environmental benefits is somewhat higher but may necessitate significant technical innovations or systemic transformations, which are often difficult to implement in practice [39].

In contrast, implementing sufficiency requires the least investment, as typical measures like dematerialization or extended product lifetimes can often be achieved at lower or nearly neutral costs, with accepting moderate market growth [21]. Although the environmental benefits of sufficiency may be somewhat lower than those of the consistency strategy, the lower costs generally yield a greater positive environmental effect per dollar spent. For instance, the German company Miele is an example for sufficient product designs, with (among other appliances) long-lasting and durable washing machines that accepts a modest growth rate resulting by their sufficient product designs [40]. This underscores the functionality of business models that ensure financial viability through sufficiency-driven products. Niessen and Bocken [21] provide a framework for sufficiency-

oriented business strategies, highlighting product-service systems, which have been under development for some time but require a shift in product design to maintain consumer appeal under new, sustainable business models. In general, by implementing sufficient product designs, the adoption of other business strategies become necessary to maintain long-term economic continuity, with service systems playing the pivotal role [21].

In summary, sufficiency presents sustainable economic continuity potential by generating revenue through models independent of material consumption, such as shared economy frameworks. While efficiency requires significant investment with limited environmental returns, consistency offers the highest environmental potential long-term, though with some economic uncertainties.

4.3. Sufficiency Engineering

To make sufficient products economically viable in the long term, it is crucial to understand the mechanisms behind why sufficient products are satisfying, how they can contribute to long-term customer loyalty, and what corresponding business models would look like. To illustrate this, the categorization of the three identified SPPs "recyclability," "product longevity," and "carbon footprint information" - within the Kano Model can be examined, with a more refined formulation of the horizontal axis (SPP fulfilled/not fulfilled), as shown in Fig. 3.

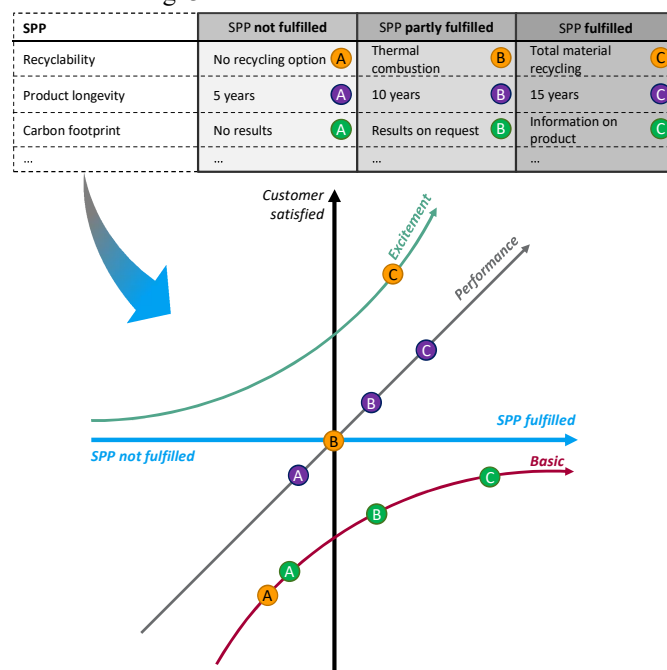


Fig. 3. Different degrees of fulfillment of SPPs and their positioning in the Kano Model.

5. Conclusion & Outlook

This paper addresses the research question of how sufficiency-oriented products can be designed to foster customer excitement, thereby promoting sustainable consumption behaviors. In response, we proposed the concept of Sufficiency Engineering, presenting it as a pathway to both

exciting and profitable sustainability. This approach was reinforced through the collection and proposal of SPPs and the identification of several design strategies aimed at embedding sufficiency principles in product development. Leveraging the Kano Model, the study illustrates how sufficiency attributes can be positively positioned in development to appeal to customers and designers. Thereby, the use of the Kano Model can enhance decision-making by illuminating how sufficiency-oriented features contribute to consumer satisfaction.

In moving forward, validating the placement of the fulfillment of SPPs within the Kano Model based on customer surveys could offer insights into their effectiveness in generating satisfaction. Additionally, the operationalization of Sufficiency Engineering within the product development process would establish practical frameworks to help businesses navigate the transition toward sustainability. Even though this contribution focuses on environmental effects, Sufficiency Engineering can also lead to social improvements, as sufficiency-oriented products are well-suited to meet the basic needs of people at the base of the social pyramid.

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