sustainability

MDPI

Article

Nurture: A Novel Approach to PSS-Rebound Effect Identification

Salman Alfarisi [1], Yuya Mitake [2], Yusuke Tsutsui [3], Hanfei Wang [1] and Yoshiki Shimomura [1,*]

[1] Faculty of Systems Design, Tokyo Metropolitan University, Tokyo 191-0065, Japan; alfarisi-salman@ed.tmu.ac.jp (S.A.)
[2] Research into Artifacts, Center for Engineering, School of Engineering, The University of Tokyo, Tokyo 113-8656, Japan; mitake@race.t.u-tokyo.ac.jp
[3] Faculty of Computer Science and Systems Engineering, Okayama Prefectural University, Okayama 719-1197, Japan; tsutsui@cse.oka-pu.ac.jp
* Correspondence: yoshiki-shimomura@tmu.ac.jp

Abstract: The product–service system is a significant research subject related to business model innovation and sustainability. However, the product–service system feature has affected the consumption behaviour, affecting nurture. The authors identified an apparent knowledge gap in the prior literature concerning nurture in the product–service system. This study examined whether nurture should be a prominent issue in the product–service system since certain features can significantly affect the achievement of set targets by generating a rebound effect. This study demonstrated that the business model system is complex, with interconnected solutions and issues. Solutions are not implemented in isolation, therefore, each decision affects the system. This study employed feedback system thinking using system dynamics. To validate its findings against the actual situation, this study employed car-sharing as a case study. The findings of this study indicate that the variable of nurture is a significant indicator of profit growth but generates a deterioration in the environmental and social performance of product–service system implementation, which leads to a rebound effect of the product–service system.

Keywords: nurture; product–service system; rebound effect; sustainability; dematerialisation; system dynamics

Citation: Alfarisi, S.; Mitake, Y.; Tsutsui, Y.; Wang, H.; Shimomura, Y. Nurture: A Novel Approach to PSS-Rebound Effect Identification. *Sustainability* **2023**, *15*, 7359. https://doi.org/10.3390/su15097359

Academic Editor: Claudio Sassanelli

Received: 17 February 2023
Revised: 22 April 2023
Accepted: 26 April 2023
Published: 28 April 2023

1. Introduction

The challenge of reducing the environmental implications of the products from a life cycle perspective has plagued industrial enterprises over the past few decades. In the 1990s, numerous authors in an arena dominated by environmentalists contended that society would face a near-certain catastrophe unless methods were discovered to decouple economic expansion from environmental pressure [1]. During the same period, the business literature also increased interest in functional business models. The product–service system (PSS) is considered one strategy [2]. A PSS can be regarded as a market offer that includes additional services to a product's standard functionality [3]. For some authors, sustainability in terms of social, economic, and environmental factors is also included in the idea of a PSS [4]. The PSS is a research issue strongly related to business model innovation and sustainability; this subfield of research has garnered a growing amount of interest from many research streams, as Boons and Lüdeke-Freund [5] demonstrated. The basic principle is that a PSS will have less of an environmental impact than a conventional transaction in which a business manufactures products but then shifts the ownership and use responsibilities to the customer. This business model pushes companies to focus on the services and experiences that accompany the product rather than just the physical product itself. By doing this, companies may lessen their reliance on physical materials and resources, which is a crucial aspect of attaining dematerialisation.

While PSS research has been well-established for more than two decades, there is still a growing interest and a need to investigate certain facets. The idea of PSS has been extensively discussed in the literature (see, for instance, [6–8]), although the industry's adoption of such concepts seems to be relatively slow. The notion that PSS equals sustainability is a myth [9]. Nicola [10] and Vezzoli [11] concur that PSS can cause second-order effects, which they refer to as secondary effects. However, further study has revealed that the phenomenon resembles the term the "rebound effect" [12]. Tukker [13] argued that the lower cost of product access through renting and leasing (use-oriented services) may lead to undesirable effects such as shortened product lifetimes due to user carelessness [9,14]. This refers to the manner in which a series of interconnected consequences on attitudes and behaviours determine product longevity throughout the consumption phase, known as "nurture" [15]. According to Mugge et al. [1], a strong emotional connection between users and their products, or strong product attachment, can lengthen the product's lifespan. Additionally, users will take better care of their products, hence minimising the probability of failure [16].

Although the rebound effect has been recognised by several earlier researchers [17,18], there are less well-documented variables in the literature that have not been analysed for their impact on the emergence of the rebound effect. In particular, the problem identified in this study is the uncertain driver of the rebound effect during the implementation of a PSS, which has tended to be a qualitative assumption without legitimate evidence. Therefore, this study intends to assess the implementation of PSS by considering the variable of nurture and analysing its contribution to the emergence of rebound effects that can impede the attainment of targeted sustainability goals. Several prior studies support this premise, which justifies the inclusion of nurture as a variable of interest. For instance, Alfarisi et al. [12] examined car-sharing as a case study and demonstrated that some characteristics of a PSS can serve as the primary motivating factor behind the rebound effect such as the absence of ownership, affecting product attachment. Product attachment refers to a consumer's intense emotional bond or attachment to an object [19]. When the emotional connection of ownership is lost, there is a greater tendency to mistreat the object. This finding is also supported by [20] concerning emotional attachment to products and indicates that strong emotions associated with personal identity and a sense of belonging have an effect on product longevity. While there are a number of potential causes for the rebound effect, this study restricted it to technological factors (improvements in efficiency), as Herring and Sorrel [21] argued that efficiency is the most important factor in predicting the occurrence of the rebound effect.

This study employed feedback system thinking, which posits that issues and solutions are causally interconnected inside the system itself, to provide a comprehensive analysis of this issue. Sarmiento et al. [22] stated in their research that management processes and systems are crucial to consider in the context of business innovation. Thus, to optimise the potential of complex PSSs, a comprehensive understanding of the system structure is required. According to Morecroft [23], when a decision is made, there will be a consequence of the cumulative effect of earlier decisions and actions that develop in the system itself. This influence is frequently unnoticed and frequently overlooked but produces equally significant problems. In addition, due to the complexity of this assessment, the scope of this study's assessment of sustainability attainment covered indicators such as the amount of pollution, the use of natural resources, the profit ratio, and the quality of life.

The rest of this is organised as follows. Section 2 examines the theoretical foundations for developing the research questions and identifying the gaps. Section 3 describes the case study's background and the processes performed to construct the model in detail. Section 4 presents the findings. Section 5 examines the study's findings and clarifies the answers to the research questions. Section 6 summarises our findings, conclusions, and future research directions.

2. Literature Review

2.1. PSS-Rebound Effect

The product-service system (PSS) is a developing topic of study and industrial practice that focuses on the purposeful and planned coupling of products and services [24]. The ultimate purpose of PSS is to enhance a company's competitiveness and profitability [25], and one of the objectives of a PSS is to reduce product consumption through alternative scenarios of product use rather than acquisition. Customers who seldom drive, for instance, may not need to purchase automobiles but rather utilise a car-sharing system [26]. Unfortunately, as numerous scholars have observed, PSSs are not intrinsically more sustainable than products [27]. Several studies on sustainable PSSs in the previous decade have presented fairly isolated concepts, manuals, and case studies. Case study research was frequently driven by normative sustainability objectives and did not investigate the causes of poor PSS implementation [9].

Frequent emphasis is placed on the potential for PSSs to improve environmental performance by dematerialisation [9]. Even if the net resource consumption and impact are reduced, to date, social issues have mostly been overlooked in PSS sustainability research. In fact, PSS sustainability must incorporate the three fundamental pillars of sustainability (social, economic, and environmental), such that the evaluation is based on the achievement of these three aspects including the assessment of the PSS rebound effect. Initially, the rebound effect was utilised in the context of energy efficiency, but subsequent research indicated that energy efficiency must be coupled with sufficiency. Sufficiency is widely defined as minimising the consumption of products and services to better satisfy individual desires and contribute to communal objectives [21]. Instead of selling items, a PSS focuses on selling usage, incorporating the concepts of effectiveness and sufficiency. The rebound effect of the PSS happens when increases in production and consumption offset increases in the production and service efficiency and sufficiency. Researchers have recognised the complexity of RE, with direct or first-order influences resulting in indirect or second-order effects [21,28].

Inadequate identification and minimisation of the rebound effect in a system would not only impede the achievement of a PSS but also result in catastrophic failure. Kjaer et al. [29] emphasised the importance of recognising and evaluating the rebound effect during PSS implementation. Alfarisi et al. [12] built a framework to analyse the possibility of a systemic rebound impact during design by including mitigating actors. The systemic rebound effect is inevitable in implementing PSS; Vezzoli et al. [11] refer to it as an unwanted effect. Unfortunately, stakeholders have misused the rebound effect as an excuse for inaction.

The findings of the literature review on potential rebound effect drivers are summarised in Table 1. The rebound effect, according to Maxwell and Andrew [30], is induced by an unanticipated increase in consumption due to environmental efficiency interventions. According to Vivanco et al. [31], the driver is a change in efficiency that leads to a change in consumption and production factors as a result of a change in price elasticity. Using a causal loop diagram, Laurenti et al. [32] stated that the incremental innovation–obsolescence cycle is a mutually reinforcing feedback loop and identified that incremental innovation leads to a shorter product life, which then increases consumption, which is the driver of the rebound effect. In addition, Alfarisi et al. [12] demonstrated that non-ownership is the primary cause of the rebound effect. Non-ownership is believed to influence product attachment and result in changes in behaviour. Liedtke et al. [33] argued that the potential for PSS to change production and consumption systems in a manner that enables a sustainable transition must be carefully evaluated. The most likely driver of rebound effects is unanticipated user behaviour or the inappropriate implementation of potentially sustainable efficiency innovations. Other PSS researchers such as Kuo and Wang [34] and Gottberg et al. [35] concurred with Kjaer et al.'s [36] assertion that changes in consumption practices are well-known as the driver of the rebound effect while the primary driver, according to Mylan [37], is a more specific factor, namely attitude, which can influence the users' consumption behaviour during the consumption phase.

Table 1. Potential rebound effect drivers.

PSS Case	Identified Driver	Authors
Energy efficiency in cars, heating/cooling, household appliances, lighting	Behavioural responses	[30]
Car non/ownership	Changes in consumption and production	[31]
Use-oriented (car sharing) and result-oriented (photocopy machine)	Incremental innovation	[32]
Car-sharing	Non-ownership lead to behavioural change	[12]
Heating and space heating	Unanticipated user behaviour	[33]
Bike-sharing	Changes in consumption practices	[34–36]
Energy efficient lighting and low temperature laundry	Attitude	[37]

Based on these findings, the authors reached the reasonable conclusion that almost all researchers, with the exception of Laurenti et al. [32], concurred that behaviour change is the main driver of the rebound effect. Based on this finding, Alfarisi et al. [12] conducted additional research into the root causes of these behavioural modifications. The findings highlight the absence of a sense of belonging and consequently, the loss of "willingness to keep", which leads to careless use of the product during the consumption phase, as Mylan [37] further explains in detail.

2.2. Nurture

The product lifetime (PL) has been focused on in innovation, technology, processes, and systems approaches and has a strong bond with manufacturers [38]. The PL is also the consequence of acts and practices that improve the qualities and functions of products, which Cox et al. [15] referred to as "nurture". 'Nurture' is controlled by functional product durability and reflects a set of interrelated effects on the attitudes and behaviours that determine a product's lifetime during the consumption phase. The concept of 'nurture' appears to be primarily divided into individual and social environment-based factors [39]. At the individual level, the role that products play in satisfying personal needs is of critical importance in terms of the functional utility provided by a product, emotional attachment to belongings, and strong feelings related to personal identity and a sense of belonging in society [40]. Important external influences include pricing, information, product quality, and availability. In its simplest form, "willingness to keep" is inextricably linked to the consumers' perceptions of value, which result from the interaction of multiple individual and societal forces and the nature of the commodity itself [15].

In a consensus study conducted by Cox et al. [15] on thirty product types utilising the traditional business model, it was concluded that consumers wanted goods to last (i.e., not break) as long as they wanted them to last, but not necessarily longer. Consumers rated durability (a product designed to endure a long time) and functional reliability (a product that performs reliably without breaking down regardless of how long it is designed to last) differently. Functional reliability was essential for all items (even those expected to be kept for a short period), whereas consumers valued durability primarily for products they planned to keep for more than a few years. Thus far, the literature has presented the subject of nurture within the context of the traditional business model, where product ownership is shifted from the producers to consumers. Not all consumers exhibit a "willingness to keep" attitude, even when the goods are owned. In the context of a PSS, where there is no shifting of goods from the producer/service provider to the customer, this phenomenon must be a research priority as the emotional link of ownership is lost, and the propensity to treat items incorrectly increases.

2.3. Feedback System Thinking

Too frequently, decoupling efforts are ultimately undermined by unanticipated responses to the initial interventions. For example, an increase in consumption can be driven by a decrease in price as a result of advances in material and energy efficiency [20]. Increasing consumption generates negative environmental externalities such as waste and pollution. Eventually, the accumulation of waste and pollution has significant social consequences. This system behaviour results from ripple effects propagating across the system's structure. Ripple effects arise when one event generates consequences that propagate across the system and produce other ripple effects [32]. The primary cause and its repercussions are typically separated in time and place. A system's structure is composed of feedback loops and causal links generated by the interaction between the system's components.

A fundamental principle of systems including the PSS is that the behaviour of a system is essentially dictated by the attributes of the whole and not by the properties of its variables. The interactions of system variables within a closed boundary consequently form the examined types of behaviour. By comprehending the link between variables, it is possible to forecast the system's behaviour, making it simpler to propose modifications. Unfortunately, identifying variables that affect the rebound effect needs to be adequately studied, making it difficult. Traditional assessment efforts typically ignore that these single units are embedded in a much larger socio-technical system, which is subject to dynamic interactions with causal links and responses (feedback loops) from numerous socio-aspects, technical aspects, and economic aspects over time [41]. In practice, a system's variables are interdependent, and feedback system thinking may be the most effective method for explicating this complexity. Feedback system thinking is typically circular, beginning with a problem, moving to a solution, and then going back to the problem [23]. The crucial point is that issues do not simply appear and demand solutions. They result from the cumulative effect of earlier decisions and actions, which are sometimes intended, but frequently have unintended consequences. Typically, a difficulty manifests as a disparity between an important objective and the present circumstance. Those accountable for accomplishing the objective arrive at a solution in the form of a choice that results in actions and outcomes that alter the current situation. Numerous feedback is nearly undetectable in practice. They manifest themselves through unexpected side effects, resistance to change, and unexpected outcomes.

Several research studies used causal loop diagrams (CLD) and system dynamics (SD) to solve PSS issues, either as an evaluation or performance measurement approach. Generally, Sassanelli et al. [42] demonstrated, through a review of the relevant literature, that the process modelling approach is one of the methods commonly used to evaluate the system performance of a business model, which in this instance focused on a circular economy that seeks to close the circle of linear product life cycles. System dynamics is one of the PSS's three effective modelling methods [43]. While Grüneisen et al. [44] attempted to represent PSSs in system dynamics to enhance the knowledge of the PSS by combining multiple multidisciplinary fields, further research is required. Lee et al. [45] employed system dynamics (SD) to examine the dynamics from a triple bottom line (TBL) perspective to cover the multidimensionality of PSS sustainability, and their findings were positive. Lee et al. [46] focused on measuring the functional performance of a PSS using a dynamic approach in a separate study. As suspected by Vezzoli [11], Nicola [10], Tukker [13], and Cherry and Pigeon [14], studies on the utilisation of system dynamics in prior research do not appear to have provided evidence of the emergence of rebound effects. Therefore, the authors assumed that the variables contributing to the rebound effect's appearance had not been accounted for in the simulations performed. Before integrating variables were deemed to have a major effect on the appearance of the rebound effect in PSS implementation, this study examined the literature. According to the authors, this is the first study to evaluate the attainment of sustainability and identify the emergence of rebound effects using nurture in system dynamics.

2.4. Research Gap and Question

Since prior research has provided significant evidence of the rebound effect in PSS deployment, this study revealed a knowledge gap in establishing the sustainability of a PSS. Consequently, the main concern of this research is "how may the rebound effect arise during PSS implementation?" To address this question, an evaluation of the variables with the potential to induce the rebound effect must be conducted. It was discovered that "nurture" was hypothesised as a significant determinant due to the loss of emotional attachments between customers and goods that were not owned, leading to a decline in "willingness to keep". This research was then divided into the following sub-research questions:

1. Does "nurture" significantly influence the emergence of the rebound effect in PSS implementation?
2. What dimensions of the system are changed by "nurture"?

This study used a feedback system thinking approach to obtain comprehensive results.

3. Materials and Methods

This study illustrates the proposed methodology with a case study of a car-sharing system. The assessment procedure adheres to the standard steps of SD: conceptualisation, formulation, testing, and analysis [45,46]. Particular emphasis was placed in this study on conceptualisation. The proposed methodology divides the conceptualisation into three steps. The first phase, establishing the indicators, addresses the explanation of the situation. To do this, the sustainability of the PSS in each dimension perspective was specified, and the necessary perspectives on the measurable indicators were proposed. The second and third steps involve model construction. The difficulty of drawing the system models, even for experts, has been illustrated [47]. Moreover, the more complex a model for conceptualising, the more difficult it is to comprehend. In SD modelling, it is evident that a modest model provides advantages over a large model [48]. Consequently, a prevalent tendency in SD has been the use of modest models to improve comprehension. The model that was developed in this work is the sustainability of a PSS from each dimension perspective; as it is a huge and complex system with multidimensional characteristics, it can be overwhelming to evaluate everything at once. The sequential approach is illustrated in Figure 1. Following this section is a detailed explanation of each section, based on the general technique of SD, with an emphasis on the unique characteristics applicable to analysing the PSS sustainability attainment and rebound effect potential.

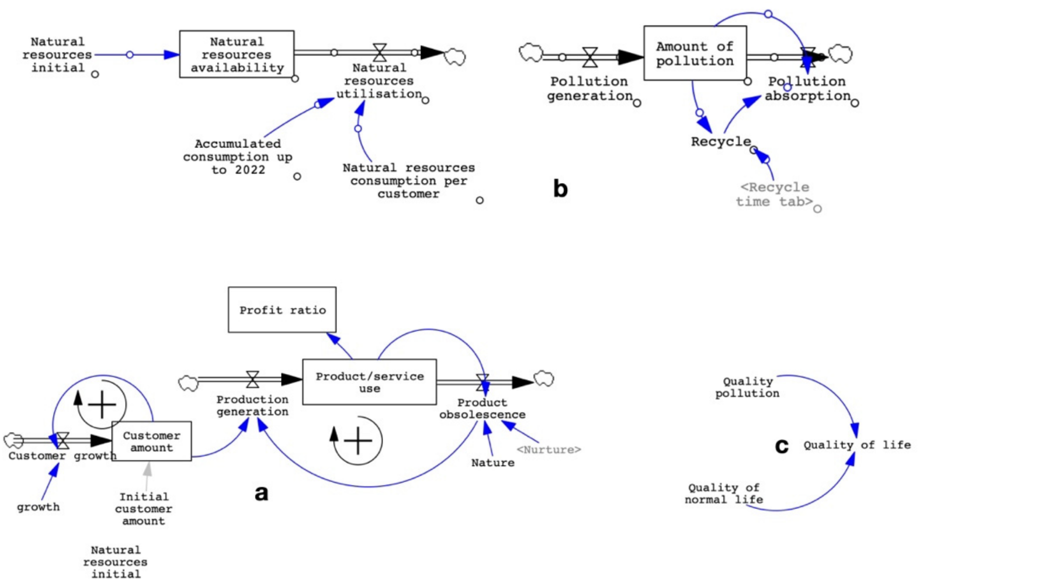

Figure 1. The partial model of PSS sustainability: (**a**) environmental dimension; (**b**) economic dimension; (**c**) social dimension.

3.1. Materials

3.1.1. Case Study Background

As sustainability has become a worldwide issue, interest in sustainable transportation systems has increased significantly. Compared to the studies performed on the perspectives and motivations of people involved in the implementation and use of car sharing in developed countries, there is limited research for those in developing countries. For instance, Java Island, the political and economic hub of Indonesia, was home to around 57% of the country's population of over 271 million in 2015 [49]. Motorcycles continue to outnumber automobiles, but the recent trend of purchasing automobiles appears to be continuing [50]. Despite the fact that bus lines including bus rapid transit (BRT) and four-wheeled minibuses or minivans (called Angkot) and taxis including unofficial two-wheeled taxis (called Ojek) are the backbone of public transportation in the Java region, the public transport system is still not fully distributed in some areas.

This background is significant for a start-up company in Indonesia wishing to launch a transportation business and adopt a more sustainable business strategy. For reasons of discretion, we refer to the company as "Me Share". This company is located in Jakarta, which remains on the Indonesian mainland of Java Island. The rapid rise of car-sharing in Indonesia is indicated by the compound annual growth rate (CAGR) of car-sharing in Indonesia, which reached 60.42 USD million by 2022, an increase of 6.24% per year [51]. In response to the increasing market competition, Me Share promises various advantages including:

- Flexible: Everyone can use the car whenever they need to.
- Simple: Reservation until the car door opens and closes; only a smartphone is required.
- Easy: Cashless and credit card payment is guaranteed to be secure.
- Well: The car is cleaned and maintained regularly so it is always ready for use.
- Affordable: Special promotions every time.

Me Share utilises a round-trip car-sharing approach, defined as a shared vehicle that begins and ends at the same location. Me Share, as a start-up company, is a service provider and collaborates with automobile manufacturers as car providers. However, as the number of customers increased, the company experienced a dilemma in which the pace of automobile obsolescence exceeded the planned life span. On numerous occasions, vehicles have been discovered to be inoperable due to engine problems. The high rate of vehicle failures has resulted in increased vehicle sales and a great demand for spare parts. Although this enhances the profit area, the company discovered a contradiction between the intended aim of car-sharing and its implementation, notably the attainment of sustainability. Considering this issue, the authors attempted to uncover probable contributory variables. Due to the business model's complexity and the system's interconnection, a system dynamics technique was applied in this study. Following the modelling process's principles, the boundary selection in this case was as follows:

- Theme: Assess the effect of nurture on the emergence of rebound effects and the attainment of sustainability in the car-sharing model business.
- Variables: Variables that contribute to the three elements of sustainability were considered. In Section 3.2.1, the three dimensions are established, and in Section 3.2.2, the variables used for each dimension are provided.
- Time horizon: This study utilised company-specific historical data from 2018 through to 2021. Then, modelling was employed to forecast the business circumstances for the years 2022–2027.

This research comprised a descriptive analysis of the company-provided dataset. The descriptive analysis provides a summary of the dataset and by using suitable statistical analysis, directed the authors to analyse potential problem drivers using a system dynamics simulation.

3.1.2. Data Collection

The purpose of this study was to investigate the existence of a rebound effect triggered by nurture with respect to the parameter of the dimension of sustainability in PSS implementation. To achieve this objective, a mixed-methods strategy using both primary and secondary data was employed. By analysing available documents, primary data were gathered directly from the company. The company's collection of primary data provided extensive insights into its operations and performance outcomes. By analysing documents such as financial statements, it is possible to gain a thorough comprehension of the factors influencing the company's performance. However, it was evident that the company lacked certain data, necessitating the use of secondary data sources. Previous research has demonstrated the significance of data integration in modelling to identify value chains, and that this process should begin internally. However, Acerbi et al. [52], after proposing a classification of data and information, suggested that awareness of the need to use both internal and external data to succeed in this path is necessary, as the absence of certain data can limit the turnover of resources, and external data can be utilised if the appropriate data are available.

Therefore, to cover this void, this study collected secondary data based on strongly related references by following the rule of the pedigree matrix. This approach involves meticulous data curation and normalisation to ensure normal distribution conformity. Using this approach, the research was able to compile a comprehensive dataset that provides a broader perspective on the company's performance.

For the reader's convenience, the data presentation was divided into three tables, each arranged according to a sustainability dimension. The data constituting the economic dimension are displayed in Table 2. The environmental dimension dataset derived from the secondary data is presented in Table 3, the social dimension dataset is displayed in Table 3, and the social dimension dataset is presented in Table 4.

Table 2. Dataset for the economic dimension.

Variable	Amount	Reference
Initial customer amount (ICA)	500,000	Company's existing data
Growth (G)	0.5 per 0.125 year	Company's existing data
Nature	10 years	Company's existing data
Nurture	[(2022,0)-(2032,1)],(2022,0),(2023,0.1),(2024,0.1), (2025,0.4),(2027,0.5),(2028,0.6),(2032,0.9),(2032,1)	Company's existing data
Available product/service in 2022	1,000,000	Company's existing data

Table 3. Dataset for the environment dimension.

Variable	Amount	Reference
Natural resources initial (NRI)	8.5×10^{13} kg	[53]
Natural resources consumption per customer (NRC)	975 kg	[54]
Accumulated consumption up to 2022 (AC 2022)	3×10^{13} kg	[55]
Production emission of car	4.56 kg CO_2 Eq./kg	[56]
Car life cycle emission	49,559 kg CO_2 Eq.	[57]
Recycling capacity	12,328,643,752 kg CO_2 Eq.	[58]

Table 4. Dataset for the social dimension.

Variable	Amount	Reference
Pollution contribution to quality of life (PCQ)	0.167	[59]

3.2. Methods

3.2.1. Define Indicators

According to research conducted by Alfarisi et al. [12], the premise of this study is that the PSS works well in one dimension but can generate problems in other dimensions in the context of sustainability. Therefore, it is essential to explain the definition of the sustainability dimensions. Depending on the objective and specific measurement purpose, several sustainability-based indicators have been proposed and implemented. Focusing on the firm's activities, numerous sets of indicators for analysing and reporting sustainability have been proposed and widely used by businesses worldwide [60]. Labuschagen et al. [61] proposed a framework for hierarchical business sustainability indicators at the industry level. In addition, research has been undertaken on measuring the sustainability of technology [62]; the accepted sets of indicators adhered differently to the specific goal of measurement.

According to Roy [63], the concept of sustainability cannot be easily described in operational terms; rather, it must be intuitively understood. Despite varying definitions and meanings, sustainable development refers to quality development that "promotes harmony between humans and between humans and nature" [64]. To assess the sustainability of the PSS and the systemic rebound effect, each dimension's sustainability—environmental, economic, and social sustainability—must be specified according to Table 5. Each definition reflects the systematic characteristics of a PSS and the contextual variables of PSS adoption as a replacement for an ownership-based consumption pattern.

Table 5. Definition of PSS sustainability attainment.

PSS Sustainability Dimension	Definition
Environmental	The production and consumption patterns of PSS are capable of limiting the depletion of natural resources due to dematerialisation and minimising the pollution existing than existing products.
Economic	PSS is able to preserve the company's economic motive in a sustainable manner.
Social	PSS can preserve the quality of life without sacrificing social rights.

Indicators for the Me Share system's sustainability were defined for the three dimensions. In this study, only the four indicators listed in Table 6 are included. For environmental sustainability, two indicators were considered: natural resource consumption and the amount of pollution, with an emphasis on reduction as a relative term rather than an absolute quantity. The profit ratio was also assessed for economic sustainability based on the assumption that the car-sharing system is geared toward private car owners. Among the different public welfare-related indicators, quality of life was seen as an indicator of social sustainability.

Table 6. Definition of PSS sustainability attainment.

PSS Sustainability Dimension	Indicator
Environmental	Amount of pollution Natural resources consumption
Economic	Profit ratio
Social	Quality of life

3.2.2. Build the Partial Model

Much of the art of SD modelling is in identifying and describing the feedback process that affects the system's behaviour [47]. Developing a model, however, requires extensive knowledge and a comprehensive understanding of the system. Assessing a PSS's sustainability entails analysing various aspects, which becomes more complex as the system expands; this is how sustainability is measured. The step-by-step method is useful to comprehend a huge and complicated system from several viewpoints: first, create a partial model, and then an integrated one.

The integrated models include the fundamental and common notion of indicators for measuring PSS sustainability as well as typical correlations between them, indicating the relevance of SD and sustainability for measuring PSS attainment. From the definition of PSS sustainability shown in Table 5, several critical aspects for establishing indicators were obtained; these were used to develop the integrated models for partial systems. Based on the defined indicators, straightforward causal links were identified within each dimension. The indicator value change was attributed to the variable 'usage of the car-sharing system'.

Economic Dimension

The parameters were derived from product/service consumption and profitability. The parameters were derived from the consumption and profitability of the product/service. Since the number of customers will affect the production generation rate, the first stage is to estimate the number of customers for the following five years. Over the next five years, the expected number of customers is calculated using an integral customer growth function with a growth value of 50% and a current initial customer count of 500,000. System behaviour demonstrates that customer growth and customer number are interdependent in this situation. This pattern indicates a relationship is reinforcing: the larger the number of customers, the greater the customer growth, and vice versa. In addition, normally, the number of products/services produced is proportional to the number of customers, but since the PSS has been shown to significantly increase vehicle utility, it means that the same vehicle can be used by four different customers, resulting in a much smaller amount of production generation than the conventional business model. The originality and novelty of this study lie in the fact that it models the product obsolescence rate not only through planned obsolescence/nature but also nurture, which refers to the influences of attitudes and behaviours that affect a product's lifetime during the consumption phase. Intriguingly, nurture is a new variable that can alter the overall simulation results, where the rebound effect is ultimately identified. Due to the absence of emotional attachments and a sense of belonging, the contrast in features between the PSS and conventional business models—where there is no transfer of ownership in car-sharing—significantly alters consumer behaviour towards the product/service. In this study, historical data were used to model nurture. High retentiveness (following guidance, affixing a sense of belonging and providing simple technical care) can enhance the vehicle's lifespan by ten years. Medium willingness to retain (guideline followed, no additional care) can lengthen the vehicle's lifespan by five to six years while with a low desire to retain (use carelessly without regard for the instructions), the vehicle only lasts one to two years. The rate of product obsolescence impacts the use of the product or service within the producer's expected lifespan. The profit is calculated using the profit ratio method [65], where the ratio value is derived by dividing the profit region's area by the profit region's area plus the loss region's area, yielding a ratio of 0.9238, hereafter known as the profit area constant. In addition, the profit ratio is the result of the ratio's value and the quantity of the product/service used. Table 3 presents the input data utilised for the economic dimension. In addition, Equations (1) and (2) demonstrate the equations needed to determine the customer number and profit ratio, respectively. Figure 1a depicts the economic dimension model

$$\text{Customer number} = \text{ICA} \int \text{customer growth.} \tag{1}$$

$$\text{Profit ratio} = \text{profit area constant} \times \text{product/service use} \tag{2}$$

Environmental Dimension

The parameters and their relationships were derived from the perspective of the existing PSS. The environmental dimension was considered from both the upstream and downstream perspectives. Upstream is the use of natural resources that affect the availability in nature, while downstream is the amount of pollution generated. However, as a commitment, the car-sharing system seeks to minimise pollution by increasing the utility of cars that can decrease the production number and by controlling the amount of pollution with a recycling policy. This model considers the recycling policy with the term "pollution absorption policy". In car-sharing, the material is concentrated iron, as it provides 64% of the car's weight [54]. Approximately 975 kg of iron is required for a standard-sized family vehicle. Although the Earth has a relatively significant iron content, its rapidly increasing use has to be a concern because iron is a non-renewable resource. The estimated quantity of an identified resource that meets the specified minimum physical and chemical criteria in relation to current mining and production practices including those for the grade, thickness, quality, and depth is 180 billion metric tonnes of crude ore with 85 billion metric tonnes of iron ore [53]. The data show that the average utilisation of iron ore is two billion metric tonnes per year. This study implies that around 30 billion metric tonnes of iron ore have been consumed since the 1950s, when the world industry peaked. "Natural resource utilisation" refers to the current utilisation of iron compared to its accumulated usage in the period. Additionally, this sum fluctuates as the number of customers grows. Since it is known that a PSS can increase vehicle utility by up to four times, natural resource consumption follows this premise. The gap between natural resources that are available in nature and those that have been consumed is termed "natural re-source availability". Table 4 presents the input data utilised for the environment dimension. Equations (3) and (4) present the calculation of natural resource availability and its derivatives.

$$\text{Natural resources utilization (NRU)} = (\text{Customer number} \times \text{NRC}) + \text{AC 2022} \tag{3}$$

$$\text{Natural resources availability (NRA)} = \text{NRI} - \text{NRU} \tag{4}$$

The simulation downstream focuses on the amount of pollution discharged into the environment. The value of "pollution generation" is calculated by multiplying the number of products/services used by the amount of pollution produced by a medium-sized vehicle throughout the period of its life cycle [56,57]. The units for measuring the pollutant output are kg CO_2 Eq. Since pollution is measured in kg CO_2 Eq., this simulation's recycling process utilised the same units to make detecting the amount of recovered pollution easier. The recycling strategy is evaluated based on the annual CO_2 quota that Indonesia can accommodate, which is 12,328,643,752 kg CO_2 Eq., and then the quota becomes a function for the subsequent pollution recycling procedure (Kojima, 2017). The amount of pollution is the difference between the amount of pollution generated and the amount of pollution absorbed. Equation (5) presents the calculation for the amount of pollution. The environmental dimension model is shown in Figure 1a.

$$\text{Amount of pollution} = \text{Pollution generation} - \text{pollution absorption} \tag{5}$$

Social Dimension

Typical factors such as the number of customers, availability of natural resources, and pollution that have been identified in the literature as being associated with quality of life were provided. The quality of life is obtained by dividing the "quality of normal life" by the "quality pollution". The ideal quality of normal life's is 100%. "Quality pollution" refers to the extent to which pollution affects the quality of life. "Natural resources availability" divided by "product/service use" multiplied by "amount of pollution" multiplied by 0.167 provides the value of quality pollution. As stated by Fuller et al. [59], pollution contributes to one out of every six deaths worldwide; hence, a value of 0.167 was used to assess the impact of pollution on the quality of life. Table 5 presents the input data along with Equations (6) and (7), which indicate the quality pollution and quality of life assessments. The social dimension model is illustrated in Figure 1c.

$$\text{Quality pollution} = \left(\frac{\text{NRA}}{\text{product/service use}}\right) \times (\text{Amount of pollution} \times \text{PCQ}) \quad (6)$$

$$\text{Quality of life} = \frac{\text{Quality of normal life}}{\text{Quality pollution}} \quad (7)$$

3.2.3. Model Integration

The partial models for the three sustainability dimensions were incorporated into the final model. To integrate these three partial models, additional variables and relationships were introduced based on the overlapping variables and relationships in the component models. Many works have identified the interrelationships among the three dimensions of sustainability [11,66]. Figure 1 depicts the integrated model illustrating typical relationships between the three pillars of sustainability for PSS sustainability. The employed linkage can be set with parameters and causal relationships based on the indicators defined for each component of PSS sustainability. As depicted in Figure 2, the partial models were incorporated into the unified model at this step. The causal structure was completed by identifying and utilising the linking factors between the dimensions. The integrated models identified positive (reinforcing) feedback loops of the upstream environment and economic dimensions.

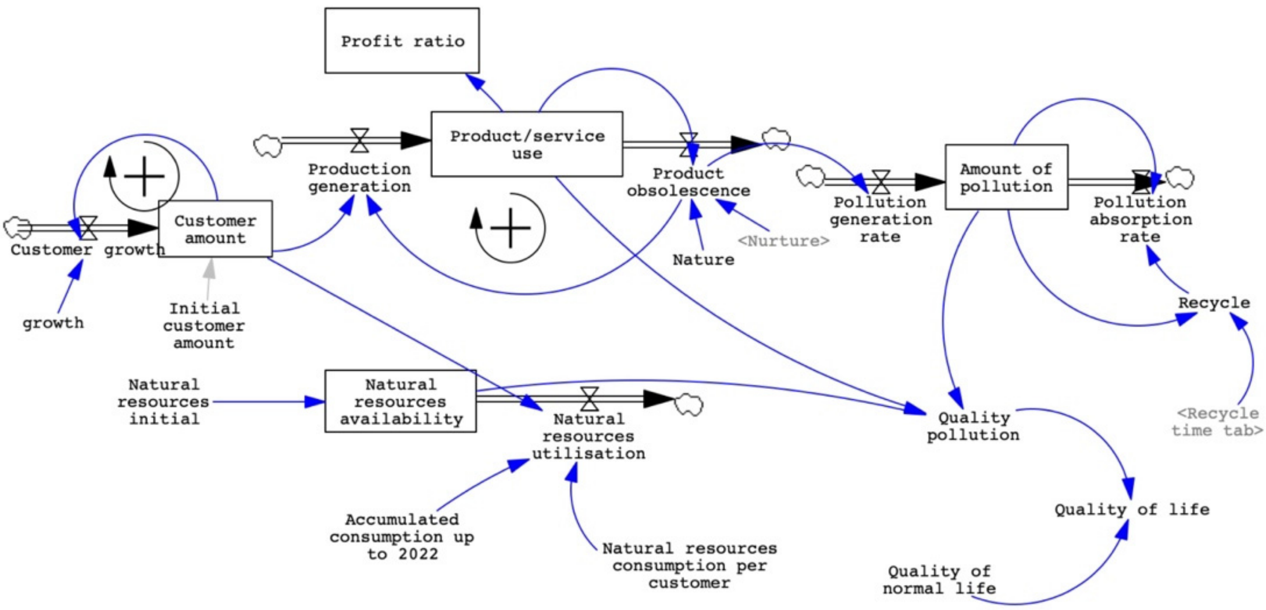

Figure 2. The integrated model of PSS car-sharing.

During the process of model integration, it was discovered that all dimensions are interconnected. For instance, the rate of product obsolescence in the economic dimension is an indicator that influences the rate of pollution generation, which in turn affects the amount of pollution. Increasing customer demand influences the availability of natural resources through the natural resource utilisation rate in the environmental dimension. Likewise, the availability of natural resources and the level of pollution impact the social dimension of life quality. Vensim software was utilised for this case study since it enables the integration of variables from other view-named shadow variables.

4. Simulation Results

Conceptually, to simulate the model, stocks describe the material or other accumulations; they are the system's states. The quantitative model's notation is dependent on the software. In terms of PSS sustainability, each sustainability indicator can be viewed as a stock variable that reflects the status of the PSS, although this is not always the case. The figure depicts the relationships between the variables using quantitative equations. This stock and flow diagram was simulated using the initial values of several variables.

The sustainability of each dimension was measured based on the long-term behaviour of each indicator, which may be displayed as a stock variable illustrating the state change of PSS from a sustainability perspective. However, a comprehensive view should be assumed on the interpretation of these data as the support they offer goes beyond just continuing with PSS, if sustainability is measured as good from all perspectives of sustainability and not continuing if not. The strength of this strategy resides in the simulation technique's capacity for intensive study. This provides strategic insights for rethinking the PSS concept: the attained levels of sustainability for the three dimensions may be set differently depending on the intended use.

This section presents a case study of the car-sharing system to demonstrate the assessment of PSS sustainability attainment. As energy and the environment have been highlighted as global challenges, a green transportation system has attracted considerable interest. The car-sharing system has been widely embraced as an example of a green transportation system in many places around the world. The business model for car-sharing is essentially the same everywhere; however, the following details are based on situations in Indonesia.

Moreover, this scenario is appropriate for demonstrating the operation of the proposed approach since it considers the environmental objective and the economic and social repercussions due to its public nature. Despite the fact that the case study was based on a real business that reflects the context of a car-sharing system, in order to achieve a simple and understandable illustration that focuses on the purpose of the case study, certain assumptions were made; the number of measured indicators and the scope of the presented model were reduced. In addition, for the data of some contextual variables, behaviour patterns were hypothesised based on indications from the literature and previous cases. The specifics of the presumed environment are described in each pertinent step.

The generated model in the stock and flow diagram was prepared for execution. However, verifying the model to prevent simulation errors would be preferable. Errors in the model will result in inaccurate simulation results, or fatalities will prevent the model from being simulated. The variables associated with policy and circumstance were quantified. However, for factors that cannot be designed by the PSS structure, some assumptions were made based on empirical evidence from the literature review [59,65,67]. The quality of life approach of Fuller et al. [59] showed, for instance, that pollution is responsible for one in every six deaths worldwide. The statement was then quantitatively translated for simulation purposes. As demonstrated by Lee et al. [46], this type of hypothetical approach has been widely employed to maintain the model's integrity in various simulation forecasts.

Figure 3 depicts the results of the simulation. The simulation results are extremely intriguing for future discussion to obtain an objective evaluation of the sustainability of PSS car-sharing and to undertake additional research on the formation of the rebound effect. The complete simulation results are presented in Table A1 (Appendix A).

The results of the simulation showed that there was an exponential increase in profit, which was influenced by the increase in product/service use. Furthermore, the increase in product/service was affected by two main factors, namely, the increase in product obsolescence and product generation. This increase in profit area is certainly a good achievement for the company if viewed from one dimension alone. Unfortunately, this increase in profit area was not accompanied by an increase in other dimensions of the sustainability dimension. The results of this study show that the amount of pollution increased significantly following the increase in the profit area. Although recycling strategies have been adopted for the waste generated, the rate of increase in product/service usage and the faster rate of obsolescence influenced by nurture was greater than the ability to recover, resulting in an increase in the amount of pollution. In 2023, the accumulated amount of pollution is 881,178 kg CO_2 eq. However, by 2027, the forecast value of the resulting amount of pollution will reach 3,129,180 kg CO_2 eq. This shows that various reactive strategies such as recycling are currently not sufficient to reduce the rate of increase in the amount of pollution generated because the amount of pollution in the system is influenced by the pollution absorption rate and the pollution generation rate. The increase in the amount of pollution shows that the pollution absorption rate is not faster than the pollution generation rate, which is directly affected by product obsolescence. Meanwhile, product obsolescence in PSS is strongly influenced by nature and nurture, which can accelerate the rate of product obsolescence. In other environmental simulations, namely, natural resources, there is a decrease in the availability of natural resources. Although this decrease is not captured clearly through numerical calculations due to the large reserves of natural resources, the high consumption of natural resources in the long run is very influential for the next generation. The availability of natural resources, in addition to being influenced by the reserves available on Earth, is also influenced by the increase in its use. Based on the simulation results, the consumption of natural resources needed for 5 years alone will reach 1.3 million metric tons, which will greatly affect the availability of natural resources. Furthermore, in an effort to assess the social dimension, this research evaluated the quality of life outcomes. Quality of life is affected by "quality pollution", which refers to the extent to which pollution affects the quality of life, while quality pollution is affected by the amount of pollution, product/service use, and the availability of natural resources. The simulation results for this social dimension are quite interesting, as the business model run with the PSS looks very promising for the first few years. The graph of the quality of life improvement continues to increase since being implemented, but soon the curve showed that social performance will decrease in the following years. The cause of this decline is certainly influenced by various structures in the system that are interrelated with each other, either due to the increase in pollution that cannot be counteracted by the recovery quota or the unstoppable increase in product obsolescence caused by nurture.

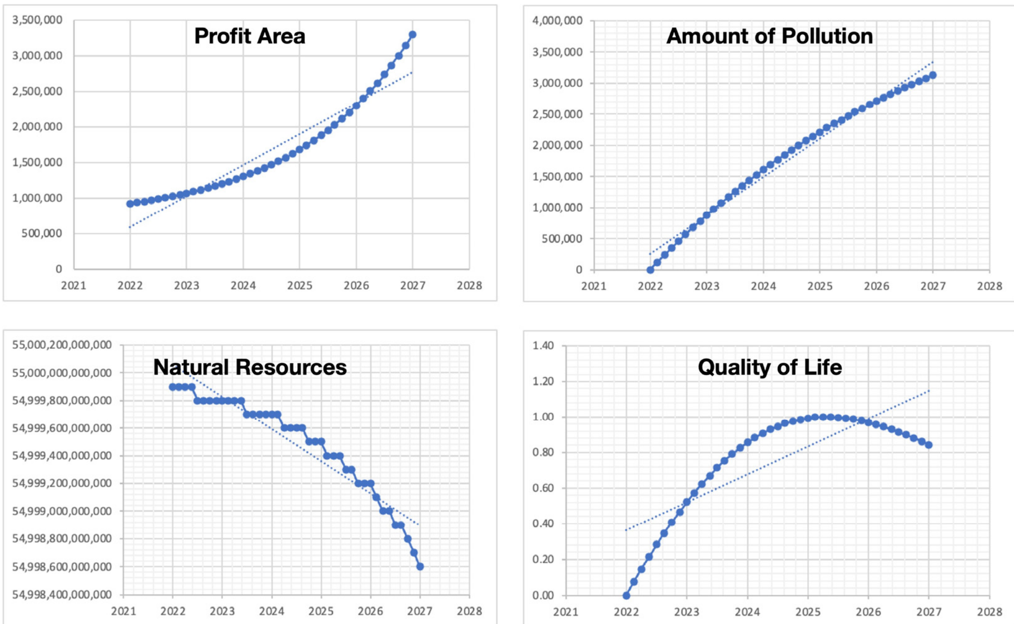

Figure 3. Simulation results of PSS car-sharing.

This finding shows that the characteristics of the PSS are not always suitable for implementation in various situations and conditions. In this case, ownership decreased the emotional attachment of users, causing the problems captured through nurture in this study. Furthermore, this study clearly showed that there was a rebound effect in the implementation of the PSS, where positive improvements only occurred in the area of increasing profits, but the achievement of sustainability targets decreased in all other aspects. The results of this study show that a systemic approach in the implementation of PSS is needed because each variable in the system is interrelated with each other and influences each other so that they cannot be separated.

5. Discussion

5.1. The Influence of Nurture on the PSS

Decades before this study's inception, Nicola asserted that PSS had the potential to cause ecological damage, as characterised by second-order effects. Several additional scholars began to recognise the emergence of rebound effects, utilising distinct terminology. However, Herring and Sorrel [21] clearly described the distinction between the rebound effect and side effect in terms of terminology. The side effect, which was utilised by previous scholars, is an element of the rebound effect. Examining the rebound effect on PSS implementation, this study took Herring and Sorrel's perspective. However, no study has currently assessed the rebound effect in PSS implementation, which can result in trade-offs. By incorporating nurture as a new variable, this study was the first to simulate the formation of the rebound effect in PSS implementation, according to the authors.

The nurture variable has emerged as a new variable where it has become a logical consequence of PSS where there is no transfer of ownership; hence, consumer behaviour will unquestionably alter. After incorporating these consumption-phase behaviour patterns into the simulation, the results indicate a significant change in system performance. Figure 4 illustrates the comparison of sustainability attainment. When nurture is incorporated into the calculation, a fundamental difference is recognised and shown by the formation of the rebound effect. The positive achievement in the economic dimension is indicated by the variable in the profit ratio that has increased over the years. The increase in the profit ratio is attributable to a rise in the product/service use. At this point, it is evident that the production generation and product obsolescence variables are responsible for increased product/service use (see Figure A1 in Appendix A). In detail, product obsolescence is influenced by the primary factor, nurture, which accelerates the pace of obsolescence as well as the nature and product/service use, which constitute a feedback loop. While production generation is driven by the increase in the number of consumers and product obsolescence, as illustrated in Figure A2, the number of items that must be generated increases with the rate of obsolescence and the increase in customer amount. However, this growth has the effect of increasing the amount of pollution produced, thus harming the environmental dimension. This study demonstrated that the increase in pollution was due to two factors: the pollution generation and pollution absorption rates. The faster a product is consumed, the quicker it must be replaced in order to continue providing services to consumers, resulting in greater pollution. As depicted in Figure A3, pollution generation is directly caused by product obsolescence, whereas pollution absorption is affected by the recycling capacity and the amount of pollution itself, creating a feedback loop. In the first two years of the social dimension, it appears promising to improve the quality of life by lowering the number of items, thereby reducing the consumption of natural resources and the amount of pollution. Nevertheless, the gain in the social dimension was short-lived. Considered characteristics that influence the quality of life include the availability of natural resources [46], pollution [68], and population/consumers [46], as illustrated in Figure A4. Unfortunately, the results of natural resource availability could not be accurately recognised in the comparative simulation. The ample supply of iron in the earth may be a contributing factor as well as the absence of a direct relationship between nurture and natural resources in the simulation as the loop cycles along the economic path (see Figure A5). This should be the focus of future studies. However, according to the authors, this event is consistent with Vezzoli's [11] definition of unwanted side effects.

Figure 4. The comparative of sustainability attainment.

This study finally demonstrates that the PSS business model is improving the economic dimension reflected by the indicator for the profit area, where growth is exponential. In contrast, the social dimension, as measured by the quality of life indicator, appears promising in the early years and peaks in March 2025. The following year, however, the performances will decrease. In the context of the study of system dynamics, this pattern parallels the overshoot and collapse pattern. An essential premise of growth is that the carrying capacity of the environment is fixed. In reality, one of the factors that determines the quality of life is the support of natural resources and the generation of products, which is speeding up due to the obsolescence affected by the change in customer behaviour due to non-ownership. In the environmental dimension, the amount of pollution increases linearly with the rate of product generation as a result of either a growth in the number of existing customers or the number of new customers.

5.2. Comparative Analysis

In the environmental dimension, the amount of pollution was the assessed indicator. Figure 4 demonstrates that the curve was nearly linear when nature was included. To comprehend the underlying structure of this expansion, the ecological idea of carrying capacity is useful. In accordance with the ecological notion of carrying capacity, the high output rate due to nurture and the growing number of customers has not been compensated by the extremely restricted recycling capacity. Increasing the recycling capacity could provide balancing feedback to increase the amount of pollution for future mitigation strategies. In contrast, when nurturing was excluded from the evaluation, the difference in the amount of emissions created was very significant. The growth of the profit area when nurture was included in the simulation followed an exponential pattern. According to Sterman [69], exponential growth is the outcome of positive (self-reinforcing) feedback. The higher the number, the greater its net increase, which will lead the number to rise exponentially. This case study indicates that the increase in profit is linked to the rise in the number of customers and product/service used. The rise in car usage is also affected by production generation, which is hastened by nurture. Positive feedback loops promote growth, amplify deviations, and encourage change, whereas the activities of negative feedback loops do not appear to be able to control a decline that is moving further away from the goal in the absence of nurturing. This study demonstrated that nurturing contributed positively to the future expansion of the economic profit area. When nurture was considered in the social dimension, which is based on the quality of life indicator, it was discovered that the pattern approached an S-shaped pattern. According to Sterman [69], a fundamental assumption behind S-shaped growth is that the environment's carrying capacity is fixed. In the simulation of this car-sharing case study, the quality of life was determined by considering the fixed availability of natural resources while the product/service use increases, resulting in a decrease in the capacity of natural availability. The amount of pollution also increased, resulting in a significant straightening of the car-sharing curve pattern in the quality of life indicator over time. In contrast, when nurture was omitted from the simulation, the quality of life increased exponentially and appeared to be quite high. However, this condition does not reflect the actual real condition because it disregards the true condition of the nurture variable.

In the same simulation, when the nurture variable was removed and a value of 5 years was only assigned to nature, the quality of life performance increased dramatically until it was comparable to that of a normal life. This is because the lower obsolescence rate was matched with a recovery capacity that could absorb low-outmoded products, allowing for optimal product recovery and a reduction in pollution. According to Buberger et al. [57], the production of a single vehicle consumes plenty of natural resources and generates a great deal of pollution. Consequently, if the rate of obsolescence is completely out of control as a result of consumer behaviour, the environmental and societal consequences will be extremely serious. In addition, simulations have been conducted to forecast the climate over the following century. The results are identical, and the loss in quality of life performance is becoming more apparent as it approaches zero, indicating a departure from normal quality of life. The complete results of the comparative simulations are presented in Table A2 (Appendix A).

5.3. Limitations

Despite its contributions and benefits, there were limitations to this study. The first was that the input data did not entirely use the available data from the case studies. The service provider's data related to economic factors such as the number of clients, the damage rate, and the number of products/services utilised. In the meantime, secondary data were utilised for information on other dimensions such as the capacity to recycle, the number of emissions during the life cycle, and the availability of natural resources. However, the procedures for using secondary data in this study adhered to the pedigree matrix approach utilised by ecoinvent to ensure data integrity and quality declaration. Some of the points considered for data collection in this study included reliability, completeness, temporal correlation, geographical correlation, and further technological correlation.

In addition, this study examined the rebound effect from the perspective of an improvement in the technical efficiency. In contrast, Walnum et al. [70] explained that there were more perspectives on the rebound effect such as psychological, evolutionary, and socio-planning, and that interdisciplinary collaboration is required to build and develop a very complex system. However, this research limited the case study to the rebound effect perspective of technical efficiency development since, as demonstrated by Santarius and Soland's [71] investigation, this perspective strongly influences customer behaviour.

5.4. Future Direction/Policy Recommendations

This study demonstrated that in the implementation of PSS, nature can no longer be utilised as a variable for determining the life cycle of products/services, as the PSS differs substantially from the conventional business model, in which product ownership is shifted. Therefore, consumer behaviour during the consumption time of the product or service fluctuates dramatically due to oscillations in the propensity to retain. Consequently, future research should investigate how to manage aftermarket behaviour. Some studies such as that by Fargnoli et al. [72] on use-oriented manufacturers have demonstrated the importance of aftermarket services for optimizing the product life cycle. Some actions such as technical assistance network ownership can contribute to the achievement of a circular economy.

Other research has highlighted the significance of implementing policies to slow the rate of change in consumer behaviour. Vivanco et al. [31] and Maxwell [30] proposed a bonus-malus scheme policy, also known as feebates or taxes, which is a variant of an environmental tax in which subsidies are used to incentivise environmentally conscious decisions and attitudes, whereas Scheepens et al. [73] stated in their research that the PSS had a "double objective" consisting of reduced environmental costs and increased value. Scheepens et al. [73] proposed an eco-efficient value creation policy to assist in avoiding a number of the risks associated with a circular business model design (e.g., having positive outcomes at the product level, but having negative effects at the social level; having positive effects on the environment, but not having enough customer-perceived value to overcome intense market competition). In contrast, Sassaneli et al. [74] showed that the high level of abstraction of PSS concepts and a lack of attention to knowledge management could be a problem during the life cycle phase and proposed a method called GuRuMeth, which utilises a circular economy approach to detail the design stages and identify its impact at various phases of its life cycle, so that it can be used as a new approach to prevent this problem during the design phase. This research was founded on the concept of design for X (DfX) in an in-depth study by Sassanelli et al. [75] that resulted in design for product service supportability.

Product–service systems (PSSs) are complex systems that necessitate a cautious policy selection strategy. Although the policies proposed by previous researchers are sound, for future direction, it is necessary to consider the complexities of the PSS. Due to the unique characteristics of a PSS, it is essential to consider potential policy restrictions and unintended consequences. Therefore, careful consideration should be given to the selection of policies that can be adapted to particular circumstances. Simulations can help identify prospective problems and provide insights into the optimal policies that can be adapted to specific contexts. In general, while the proposed policies provide a useful framework, they must be carefully selected, implemented, and evaluated to ensure that they achieve their intended goals.

6. Conclusions

This study proposed a dynamic and multidimensional approach to the measurement of PSS sustainability by using a creative combination of SD and sustainability dimensions, with the primary objective of identifying sustainability achievements and detecting potential rebound effects caused by the policy itself. Consequently, this approach may be used to determine the long-term sustainability behaviour of a PSS that considers the interdependencies among the three pillars of PSS sustainability, to identify trade-offs between dimensions, and lead to rebound effects. Furthermore, as a dynamic and multidimensional assessment indicator that considers the sustainability characteristics of a PSS, this method can be used effectively to evaluate numerous PSS solutions or to analyse the concept of PSS including the potential rebound effect in the PSS, which can negate the benefits of PSS due to greater negative impacts during the implementation phase. This study indicates a growth in profit area from 923,080 in 2022 to 3,300,000 in 2027. In addition, the forecasted value of the quantity of pollution generated in 2027 is 3,129,180 kg CO_2 equivalent, and the required consumption of natural resources for five years is 1.3 million metric tons, which has a significant impact on the availability of natural resources. The results of the simulation for the social dimension are quite intriguing, with the PSS business model appearing to be very promising in the first few years. The graph of improved quality of life since implementation continues to rise, but in the subsequent years reveals a decline in social performance. This study confirms that nurture should be a prominent issue in a PSS since certain PSS features can significantly affect the achievement of set targets.

This study identified a discernible knowledge gap in the earlier study on nurture in a PSS. Therefore, the rebound effect could not be accurately identified since previous research did not consider nurture in the PSS evaluation. Consequently, the novelty of this study resides in its capacity to comprehensively identify rebound effects that account for nurture and quantify the influence of all behaviours on the system structure through sustainability parameters. In terms of knowledge and the theoretical foundation, this research contributes to closing the knowledge gap on the elements that significantly contribute to the rebound effect and trade-off of sustainability outcomes during PSS implementation since, to date, no PSS research has focused on environmental variables that cause product obsolescence. While the contribution of this research to the industry is its ability to detect the impact of every measure on the rebound effect so that policymakers must be more cautious, for instance, during the period of product use by customers, this study is additionally applicable to forecast future PSS attainments and the potential emergence of rebound effects of the business. In addition, the results of this study serve as a warning to industries that have previously believed that implementing a PSS will inherently result in sustainability. The industry reacted positively to this result, particularly its ability to predict the conditions for attaining sustainability in the coming years. The adopted systemic approach demonstrates convincingly that every decision has an effect on all aspects of the system. In addition, the industry regards the results of this study as a starting point for developing new policies to control the pace of customer behaviour change.

It should be noted, however, that this research was conducted in the context of car-sharing, where emissions and the consumption of natural resources are high enough to have a significant impact on the entire system if the life cycle is shortened; thus, this simulation cannot be generalised to all cases. Furthermore, the case study of the public car-sharing system is important as an illustration of comprehensible settings, and the underlying assumptions limit the applicability of the conclusions. In light of this, it is worthwhile for future studies to focus on enriching and systematising the indicators for each dimension and for the interrelationships between dimensions to enhance the data collection based on the literature and the case study used in this study. Additional development and validation by established practises for system dynamics modelling is required to yield more definitive results.

Author Contributions: Conceptualization, S.A.; Methodology, S.A.; Software, S.A.; Validation, S.A., Y.M.; Formal analysis, S.A.; Investigation, S.A.; Resources, S.A.; Data curation, S.A.; Writing—original draft preparation, S.A.; Writing—review and editing, S.A., Y.M., Y.T., H.W. and Y.S.; Visualization, S.A.; Supervision, Y.S.; Funding acquisition, Y.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Simulation results.

Time (Year)	Amount of Pollution	Natural Resources Availability	Quality of Life	Profit Ratio
2022	0	54,999,900,000,000	0.0000	923,080
2022.12	119,639	54,999,900,000,000	0.0742	937,503
2022.25	236,428	54,999,900,000,000	0.1460	952,828
2022.38	350,438	54,999,900,000,000	0.2153	969,110
2022.5	461,739	54,999,800,000,000	0.2821	986,410

Table A1. *Cont.*

Time (Year)	Amount of Pollution	Natural Resources Availability	Quality of Life	Profit Ratio
2022.62	570,398	54,999,800,000,000	0.3461	1,000,000
2022.75	676,482	54,999,800,000,000	0.4074	1,020,000
2022.88	780,054	54,999,800,000,000	0.4659	1,050,000
2023	881,178	54,999,800,000,000	0.5215	1,070,000
2023.12	979,914	54,999,800,000,000	0.5740	1,090,000
2023.25	1,076,320	54,999,800,000,000	0.6236	1,120,000
2023.38	1,170,460	54,999,800,000,000	0.6701	1,140,000
2023.5	1,262,390	54,999,700,000,000	0.7134	1,170,000
2023.62	1,352,160	54,999,700,000,000	0.7536	1,200,000
2023.75	1,439,830	54,999,700,000,000	0.7907	1,230,000
2023.88	1,525,440	54,999,700,000,000	0.8246	1,270,000
2024	1,609,060	54,999,700,000,000	0.8554	1,300,000
2024.12	1,690,720	54,999,700,000,000	0.8830	1,340,000
2024.25	1,770,490	54,999,600,000,000	0.9076	1,380,000
2024.38	1,848,400	54,999,600,000,000	0.9291	1,420,000
2024.5	1,924,510	54,999,600,000,000	0.9476	1,470,000
2024.62	1,998,850	54,999,600,000,000	0.9631	1,520,000
2024.75	2,071,480	54,999,500,000,000	0.9759	1,570,000
2024.88	2,142,430	54,999,500,000,000	0.9858	1,620,000
2025	2,211,750	54,999,500,000,000	0.9931	1,680,000
2025.12	2,279,480	54,999,400,000,000	0.9978	1,740,000
2025.25	2,345,650	54,999,400,000,000	1.0000	1,810,000
2025.38	2,410,310	54,999,400,000,000	0.9999	1,880,000
2025.5	2,473,500	54,999,300,000,000	0.9976	1,950,000
2025.62	2,535,240	54,999,300,000,000	0.9931	2,030,000
2025.75	2,595,590	54,999,200,000,000	0.9867	2,110,000
2025.88	2,654,560	54,999,200,000,000	0.9785	2,200,000
2026	2,712,210	54,999,200,000,000	0.9685	2,300,000
2026.12	2,768,550	54,999,100,000,000	0.9570	2,400,000
2026.25	2,823,620	54,999,000,000,000	0.9440	2,510,000
2026.38	2,877,460	54,999,000,000,000	0.9297	2,620,000
2026.5	2,930,100	54,998,900,000,000	0.9143	2,740,000
2026.62	2,981,560	54,998,900,000,000	0.8977	2,870,000
2026.75	3,031,870	54,998,800,000,000	0.8803	3,000,000
2026.88	3,081,070	54,998,700,000,000	0.8620	3,150,000
2027	3,129,180	54,998,600,000,000	0.8430	3,300,000

Table A2. Comparative results.

Time (Year)	Nurture Included			Nurture Excluded		
	Amount of Pollution	Quality of Life (Normalised)	Profit Ratio	Amount of Pollution	Quality of Life (Normalised)	Profit Ratio
2022	0	0.00	923,080	0	0.0000	923,080
2022.12	119,639	0.00	937,503	5640	0.0142	900,003
2022.25	236,428	0.00	952,828	11,279	0.0289	877,503
2022.38	350,438	0.00	969,110	16,919	0.0439	855,566
2022.5	461,739	0.00	986,410	22,559	0.0593	834,177
2022.62	570,398	0.00	1,000,000	28,198	0.0752	813,322
2022.75	676,482	0.00	1,020,000	33,838	0.0914	792,989
2022.88	780,054	0.00	1,050,000	39,478	0.1081	773,165
2023	881,178	0.00	1,070,000	45,117	0.1253	753,836
2023.12	979,914	0.00	1,090,000	50,757	0.1429	734,990
2023.25	1,076,320	0.01	1,120,000	56,397	0.1609	716,615
2023.38	1,170,460	0.01	1,140,000	62,036	0.1795	698,700
2023.5	1,262,390	0.01	1,170,000	67,676	0.1986	681,233
2023.62	1,352,160	0.01	1,200,000	73,316	0.2181	664,202
2023.75	1,439,830	0.01	1,230,000	78,955	0.2382	647,597
2023.88	1,525,440	0.01	1,270,000	84,595	0.2589	631,408
2024	1,609,060	0.01	1,300,000	90,234	0.2801	615,623
2024.12	1,690,720	0.01	1,340,000	95,874	0.3018	600,232
2024.25	1,770,490	0.01	1,380,000	101,514	0.3242	585,227
2024.38	1,848,400	0.01	1,420,000	107,153	0.3471	570,597
2024.5	1,924,510	0.01	1,470,000	112,793	0.3707	556,332
2024.62	1,998,850	0.01	1,520,000	118,432	0.3949	542,424
2024.75	2,071,480	0.01	1,570,000	124,072	0.4197	528,864
2024.88	2,142,430	0.01	1,620,000	129,712	0.4452	515,643
2025	2,211,750	0.01	1,680,000	135,351	0.4714	502,752
2025.12	2,279,480	0.01	1,740,000	140,991	0.4983	490,184
2025.25	2,345,650	0.01	1,810,000	146,630	0.5259	477,930
2025.38	2,410,310	0.01	1,880,000	152,270	0.5543	465,983
2025.5	2,473,500	0.01	1,950,000	157,909	0.5834	454,334
2025.62	2,535,240	0.01	2,030,000	163,549	0.6133	442,976
2025.75	2,595,590	0.01	2,110,000	169,188	0.6440	431,903
2025.88	2,654,560	0.01	2,200,000	174,828	0.6755	421,106
2026	2,712,210	0.01	2,300,000	180,467	0.7079	410,579
2026.12	2,768,550	0.01	2,400,000	186,107	0.7411	400,316
2026.25	2,823,620	0.01	2,510,000	191,746	0.7752	390,309
2026.38	2,877,460	0.01	2,620,000	197,386	0.8102	380,553
2026.5	2,930,100	0.01	2,740,000	203,025	0.8462	371,041
2026.62	2,981,560	0.01	2,870,000	208,665	0.8832	361,766
2026.75	3,031,870	0.01	3,000,000	214,304	0.9211	352,724
2026.88	3,081,070	0.01	3,150,000	219,944	0.9600	343,908
2027	3,129,180	0.01	3,300,000	225,583	1	335,312

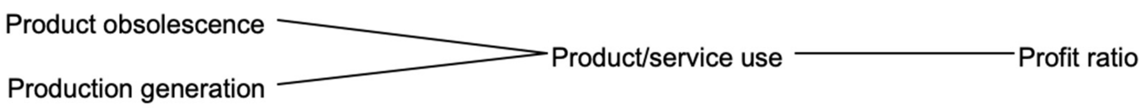

Figure A1. The causes tree of "Profit ratio".

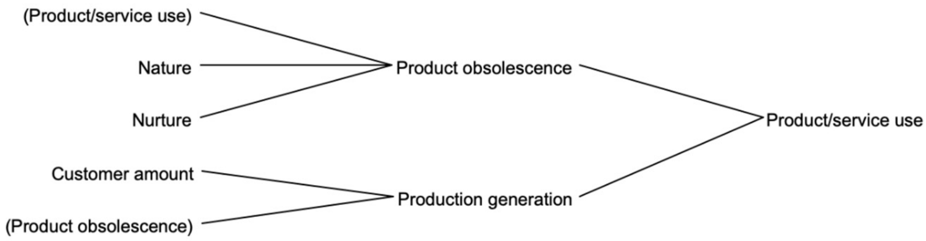

Figure A2. The causes tree of "product/service use".

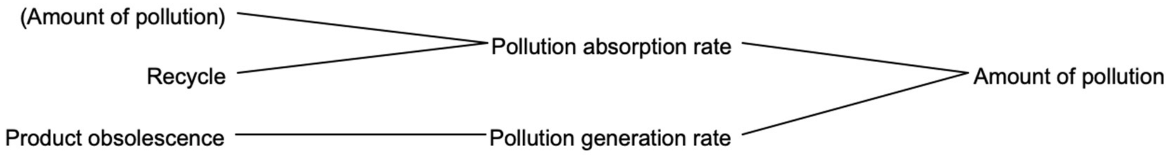

Figure A3. The causes tree of "amount of pollution".

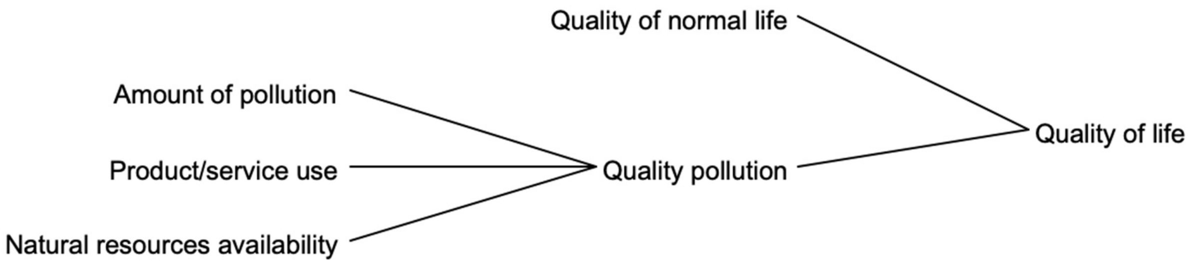

Figure A4. The causes tree of "Quality of life".

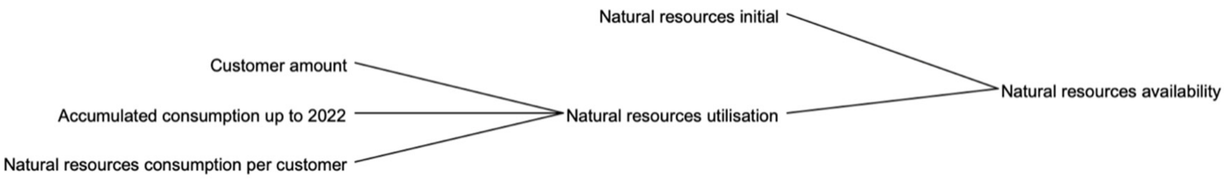

Figure A5. The causes tree of "natural resources availability".

References

1. Mugge, R.; Schoormans, J.P.L.; Schifferstein, H.N.J.; Mugge, R.; Schoormans, J.P.L.; Schifferstein, H.N.J. Design Strategies to Postpone Consumers' Product Replacement: The Value of a Strong Person-Product Relationship. *Des. J.* **2005**, *8*, 38–48. [CrossRef]
2. Bianchi, N.P.; Evans, S.; Revetria, R.; Tonelli, F. Influencing Factors of Successful Transitions towards Product-Service Systems: A Simulation Approach. *Int. J. Math. Comput. Simul.* **2009**, *3*, 30–43.
3. Mont, O. Clarifying the Concept of Product-Service System. *J. Clean. Prod.* **2002**, *10*, 237–245. [CrossRef]
4. Baines, T.S. State-of-the-Art in Product-Service Systems. *Proc. Inst. Mech. Eng. Part B J. Eng. Manuf.* **2007**, *221*, 1543–1552. [CrossRef]
5. Boons, F.; Lüdeke-freund, F. Business Models for Sustainable Innovation: State-of-the-Art and Steps towards a Research Agenda. *J. Clean. Prod.* **2013**, *45*, 9–19. [CrossRef]
6. Ponsioen, T.C.; Vieira, M.D.M.; Goedkoop, M.J. Surplus Cost as a Life Cycle Impact Indicator for Fossil Resource Scarcity. *Int. J. Life Cycle Assess.* **2014**, *19*, 872–881. [CrossRef]
7. Meijkamp, R. Changing Consumer Behaviour through Eco-Efficient Services. An Empirical Study of Car Sharing in the Netherlands. Ph.D. Thesis, Delft University of Technology, Delft, The Netherlands, 2000.
8. Manzini, E. A Strategic Design Approach to Develop Sustainable Product Service Systems: Examples Taken from the "environmentally Friendly Innovation" Italian Prize. *J. Clean. Prod.* **2003**, *11*, 851–857. [CrossRef]
9. Tukker, A. Product-Services as a Research Field: Past, Present and Future. Reflections from a Decade of Research. *J. Clean. Prod.* **2006**, *14*, 1552–1556. [CrossRef]
10. Nicola, W.; Robert, A.; Kai, H. Assessing the Rebound Effect and Other Macro Impacts of S-PSS Strategies. Presented at INSEAD-CMER, Fontainebleau, France, 9 May 2002.
11. Vezzoli, C.; Kohtala, C.; Srinivasan, A.; Diehl, J.C.; Fusakul, S.M.; Xin, L.; Sateesh, D. *Product-Service System Design for Sustainability*; Greenleaf Publishing: Sheffield, UK, 2017; pp. 1–502. ISBN 1-909493-69-4.

12. Alfarisi, S.; Mitake, Y.; Tsutsui, Y.; Wang, H.; Shimomura, Y. A Study of the Rebound Effect on the Product-Service System: Why Should It Be a Top Product-Service Priority? *Procedia CIRP* **2022**, *109*, 257–262. [CrossRef]
13. Tukker, A. Product Services for a Resource-Ef Fi Cient and Circular Economy e a Review. *J. Clean. Prod.* **2015**, *97*, 76–91. [CrossRef]
14. Cherry, C.E. Why Is Ownership an Issue? Exploring Factors That Determine Public Acceptance of Product-Service Systems. *Sustainability* **2018**, *10*, 2289. [CrossRef]
15. Cox, J.; Griffith, S.; Giorgi, S.; King, G. Consumer Understanding of Product Lifetimes. *Resour. Conserv. Recycl.* **2013**, *79*, 21–29. [CrossRef]
16. Yamamoto, H.; Murakami, S. Product Obsolescence and Its Relationship with Product Lifetime: An Empirical Case Study of Consumer Appliances in Japan. *Resour. Conserv. Recycl.* **2021**, *174*, 105798. [CrossRef]
17. Vezzoli, C. Why Have "Sustainable Product-Service Systems" Not Been Widely Implemented? Meeting New Design Challenges to Achieve Societal Sustainability. *J. Clean. Prod.* **2012**, *35*, 288–290. [CrossRef]
18. Annarelli, A.; Battistella, C.; Nonino, F. Product Service System: A Conceptual Framework from a Systematic Review. *J. Clean. Prod.* **2016**, *139*, 1011–1032. [CrossRef]
19. Demyttenaere, K. The Influence of Ownership on the Sustainable Use of Product-Service Systems—A Literature Review. *Procedia CIRP* **2016**, *47*, 180–185. [CrossRef]
20. Thiesen, J.; Christensen, T.S.; Kristensen, T.G.; Andersen, R.D.; Brunoe, B.; Gregersen, T.K.; Thrane, M.; Weidema, B.P. LCA Case Studies Rebound Effects of Price Differences. *Int. J. Life Cycle Assess.* **2008**, *13*, 104–114. [CrossRef]
21. Herring, H. Technological Innovation, Energy Efficient Design and the Rebound Effect. *Technovation* **2007**, *27*, 194–203. [CrossRef]
22. Sarmiento, P.A.Q.; Mayancela, R.; Suárez, L. Análisis de La Relación Entre Gestión de Calidad, Gestión Del Conocimiento e Innovación En Las Pymes. *Iber. Conf. Inf. Syst. Technol. (CISTI)* **2019**, *6*, 18867025.
23. Morecroft, J.D. *Strategic and Business*; John Wiley & Sons: New York, NY, USA, 2015; ISBN 978-1-118-84468-7.
24. Haase, R. Product/Service-System Origins and Trajectories: A Systematic Literature Review of PSS Definitions and Their Characteristics. *Procedia CIRP* **2017**, *64*, 157–162. [CrossRef]
25. Geng, X. An Integrated Approach for Rating Engineering Characteristics' Final Importance in Product-Service System Development. *Comput. Ind. Eng.* **2010**, *59*, 585–594. [CrossRef]
26. Kang, M. Product Service Systems as Systemic Cures for Obese Consumption and Production. *J. Clean. Prod.* **2008**, *16*, 1146–1152. [CrossRef]
27. Tukker, A.; Tischner, U. (Eds.) *New Business for Old Europe: Product-Service Development, Competitiveness and Sustainability*; Greenleaf Publishing: Sheffield, UK, 2006.
28. Berkhout, P.H.G.; Muskens, J.C.; Velthuijsen, J.W. Defining the rebound effect. *Energy Pol.* **2000**, *28*, 425–432. [CrossRef]
29. Kjaer, L.L. Guidelines for Evaluating the Environmental Performance of Product/Service-Systems through Life Cycle Assessment. *J. Clean. Prod.* **2018**, *190*, 666–678. [CrossRef]
30. Maxwell, D.; Owen, P.; McAndrew, L.; Muehmel, K.; Neubauer, A. *Addressing the Rebound Effect: A Report for The European Commission DG Environment*; European Commission: Brussels, Belgium, 2011.
31. Vivanco, D.F.; VAn der Voer, E.; Font Vivanco, D.; Kemp, R.; van der Voet, E. How to Deal with the Rebound Effect? A Policy-Oriented Approach. *Energy Policy* **2016**, *94*, 114–125. [CrossRef]
32. Laurenti, R. Unintended Environmental Consequences of Improvement Actions: A Qualitative Analysis of Systems' Structure and Behavior. *Syst. Res. Behav. Sci.* **2016**, *33*, 381–399. [CrossRef]
33. Liedtke, C.; Baedeker, C.; Hasselkuß, M.; Rohn, H.; Grinewitschus, V. User-Integrated Innovation in Sustainable LivingLabs: An Experimental Infrastructure for Researching and Developing Sustainable Product Service Systems. *J. Clean. Prod.* **2015**, *97*, 106–116. [CrossRef]
34. Kuo, T. Simulation of Purchase or Rental Decision-Making Based on Product Service System. *Int. J. Adv. Manuf. Technol.* **2011**, *52*, 1239–1249. [CrossRef]
35. Gottberg, A.; Longhurst, P.J.; Cook, M.B. Exploring the Potential of Product Service Systems to Achieve Household Waste Prevention on New Housing Developments in the UK. *Waste Manag. Res.* **2010**, *28*, 228–235. [CrossRef]
36. Kjaer, L.L. Challenges When Evaluating Product/Service-Systems through Life Cycle Assessment. *J. Clean. Prod.* **2016**, *120*, 95–104. [CrossRef]
37. Mylan, J. Understanding the Diffusion of Sustainable Product-Service Systems: Insights from the Sociology of Consumption and Practice Theory. *J. Clean. Prod.* **2015**, *97*, 13–20. [CrossRef]
38. Nes, N.V.; Cramer, J. Product Lifetime Optimization: A Challenging Strategy towards More Sustainable Consumption Patterns. *J. Clean. Prod.* **2006**, *14*, 1307–1318. [CrossRef]
39. Park, H. A Chance Discovery-Based Approach for New Product–Service System (PSS) Concepts. *Serv. Bus.* **2015**, *9*, 115–135. [CrossRef]
40. Schifferstein, H.N.J.; Zwartkruis-Pelgrim, E.P.H. Consumer-Product Attachment: Measurement and Design Implications. *Int. J. Des.* **2015**, *2*, 1–13.
41. Laurenti, R.; Sinha, R.; Singh, J. Some Pervasive Challenges to Sustainability by Design of Electronic Products—A Conceptual Discussion. *J. Clean. Prod.* **2015**, *108*, 281–288. [CrossRef]
42. Sassanelli, C.; Rosa, P.; Rocca, R.; Terzi, S. Circular Economy Performance Assessment Methods: A Systematic Literature Review. *J. Clean. Prod.* **2019**, *229*, 440–453. [CrossRef]

43. Weidmann, D.; Maisenbacher, S.; Kasperek, D.; Maurer, M. Product-Service System Development with Discrete Event Simulation Modeling Dynamic Behavior in Product-Service Systems. In Proceedings of the 2015 Annual IEEE Systems Conference (SysCon) Proceedings, Vancouver, BC, Canada, 13–16 April 2015; IEEE: Vancouver, BC, Canada, 2015; pp. 133–138.
44. Grüneisen, P.; Stahl, B.; Kasperek, D.; Maurer, M.; Lohmann, B. Qualitative System Dynamics Cycle Network of the Innovation Process of Product Service Systems. *Procedia CIRP* **2015**, *30*, 120–125. [CrossRef]
45. Lee, S. Dynamic and Multidimensional Measurement of Product-Service System (PSS) Sustainability: A Triple Bottom Line (TBL)-Based System Dynamics Approach. *J. Clean. Prod.* **2012**, *32*, 173–182. [CrossRef]
46. Lee, J. Dominant Innovation Design for Smart Products-Service Systems (PSS): Strategies and Case Studies. In Proceedings of the Annual SRII Global Conference, San Jose, CA, USA, 23–25 April 2014; pp. 305–310.
47. Richardson, G.P. Problems with Causal-Loop Diagrams. *Syst. Dyn. Rev.* **1986**, *2*, 158–170. [CrossRef]
48. Forrester, J.W. Lessons from System Dynamics Modeling. *Syst. Dyn. Rev.* **1987**, *3*, 136–149. [CrossRef]
49. Statistics Indonesia. Percentage of Population by Province and Gender. Available online: https://www.bps.go.id/dynamictable/2018/03/20/1288/persentase-penduduk-menurut-provinsi-dan-jenis-kelamin-2009-2018.html (accessed on 11 December 2022).
50. Belgiawan, P.F.; Schmöcker, J.; Fujii, S. Understanding Car Ownership Motivations among Indonesian Students. *Int. J. Sustain. Transp.* **2014**, *10*, 37–41. [CrossRef]
51. Statista. Car-Sharing Indonesia. Available online: https://www.statista.com/outlook/mmo/shared-mobility/shared-rides/car-sharing/indonesia (accessed on 7 January 2023).
52. Acerbi, F.; Sassanelli, C.; Taisch, M. A Conceptual Data Model Promoting Data-Driven Circular Manufacturing. *Oper. Manag. Res.* **2022**, *15*, 838–857. [CrossRef]
53. Statista. Reserves of Iron Ore Worldwide from 2010 to 2021. 2022. Available online: https://www.statista.com/statistics/1168572/global-reserves-of-iron-ore/ (accessed on 16 November 2022).
54. Drive Sustainability Iron Ore Value Chain. 2022.
55. Statista. Production Volume of Usable Iron Ore Worldwide from 2006 to 2021. Available online: https://www.statista.com/statistics/589945/iron-ore-production-gross-weight-worldwide/ (accessed on 17 November 2022).
56. Verwertung, H.N. Klimabilanz von E-Fahrzeugen & Life Cycle Engineering. 2019. Available online: https://www.hanswernersinn.de/sites/default/files/VW_Klimabilanz_von_E-Fahrzeugen_Life_Cycle_Engineering_0.pdf (accessed on 29 November 2022).
57. Buberger, J.; Kersten, A.; Kuder, M.; Eckerle, R.; Weyh, T. Total CO_2 Equivalent Life-Cycle Emissions from Commercially Available Passenger Cars. *Renew. Sustain. Energy Rev.* **2022**, *159*, 112158. [CrossRef]
58. Kojima, M. Vehicle Recycling in the ASEAN and Other ASIAN Countries. ERIA Research Project Report No. 16. 2017. Available online: https://think-asia.org/handle/11540/9394 (accessed on 29 November 2022).
59. Fuller, R.; Landrigan, P.J.; Balakrishnan, K.; Bathan, G.; Bose-O'Reilly, S.; Brauer, M.; Caravanos, J.; Chiles, T.; Cohen, A.; Corra, L.; et al. Pollution and Health: A Progress Update. *Lancet Planet. Health* **2022**, *6*, e535–e547. [CrossRef]
60. Lozano, R.; Huisingh, D. Inter-Linking Issues and Dimensions in Sustainability Reporting. *J. Clean. Prod.* **2011**, *19*, 99–107. [CrossRef]
61. Labuschagne, C.; Brent, A.C.; van Erck, R.P. Assessing the Sustainability Performances of Industries. *J. Clean. Prod.* **2005**, *13*, 373–385. [CrossRef]
62. Assefa, G.Ã.; Frostell, B. Social Sustainability and Social Acceptance in Technology Assessment: A Case Study of Energy Technologies. *Technol. Soc.* **2007**, *29*, 63–78. [CrossRef]
63. Roy, M. Introduction to Sustainable Development. In *Sustainable Development Strategies*; Elsevier: Amsterdam, The Netherlands, 2021; pp. 1–25. ISBN 978-0-12-818920-7.
64. WCED. *Report of the World Commission on Environment and Development: Our Common Future*; Oxford University Press: Oxford, UK; New York, NY, USA, 1987.
65. Badiru, A.B.; Omitaomu, O.A. *Handbook of Industrial Engineering Equations, Formulas, and Calculations*; CRC Press: Boca Raton, FL, USA, 2011; ISBN 978-1-4200-7627-1.
66. ESCAP UN. Integrating the Three Dimensions of Sustainable Development: A Framework and Tools. Greening of Economic Growth Series. Bangkok. 2015. Available online: https://repository.unescap.org/handle/20.500.12870/3161 (accessed on 1 December 2022).
67. Corsini, L.; Moultrie, J. What Is Design for Social Sustainability? A Systematic Literature Review for Designers of Product-Service Systems. *Sustainability* **2021**, *13*, 5963. [CrossRef]
68. Ceschin, F.; Gaziulusoy, I. Evolution of Design for Sustainability: From Product Design to Design for System Innovations and Transitions. *Des. Stud.* **2016**, *47*, 118–163. [CrossRef]
69. Sterman, J.D. *Business Dynamics, System Thinking and Modeling for Complex World*; MCGraw Hill: New York, NY, USA, 2002; ISBN 0-07-231135-5.
70. Walnum, H.J.; Aall, C.; Løkke, S. Can Rebound Effects Explain Why Sustainable Mobility Has Not Been Achieved. *Sustainability* **2014**, *6*, 9510–9537. [CrossRef]
71. Santarius, T.; Soland, M. How Technological E Ffi Ciency Improvements Change Consumer Preferences: Towards a Psychological Theory of Rebound Effects. *Ecol. Econ.* **2018**, *146*, 414–424. [CrossRef]

72. Fargnoli, M.; Haber, N.; Tronci, M. Case Study Research to Foster the Optimization of Supply Chain Management through the PSS Approach. *Sustainability* **2022**, *14*, 2235. [CrossRef]
73. Scheepens, A.E.; Vogtländer, J.G.; Brezet, J.C. Two Life Cycle Assessment (LCA) Based Methods to Analyse and Design Complex (Regional) Circular Economy Systems. Case: Making Water Tourism More Sustainable. *J. Clean. Prod.* **2016**, *114*, 257–268. [CrossRef]
74. Sassanelli, C.; Da Costa Fernandes, S.; Rozenfeld, H.; Mascarenhas, J.; Terzi, S. Enhancing Knowledge Management in the PSS Detailed Design: A Case Study in a Food and Bakery Machinery Company. *Concurr. Eng. Res. Appl.* **2021**, *29*, 295–308. [CrossRef]
75. Sassanelli, C.; Pezzotta, G.; Pirola, F.; Terzi, S.; Rossi, M. Design for Product Service Supportability (DfPSS) Approach: A State of the Art to Foster Product Service System (PSS) Design. *Procedia CIRP* **2016**, *47*, 192–197. [CrossRef]