A STUDY ON IMPROVING SUSTAINABILITY OF CLOSED-LOOP SUPPLY CHAINS WITH SOCIAL RESPONSIBILITY

(社会的責任を考慮した閉ループサプライチェーンの持続可能性向上に関する研究)

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is a series of research works by **SUMARSONO SUDARTO** during his doctoral study from April 1st 2013 to the August 18th 2016 in Production System Engineering Laboratory, Department of System Cybernetics, Graduate School of Engineering, Hiroshima University, Japan. This dissertation has been accepted as a part of requirements in conferring in a **Doctor of Engineering** degree to him.

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بِسْـــــــمِ اللهِ الرَّحْمَنِ الرَّحِيم

"I testify that (there is) no god except God; One is He, no partner has He, and I testify that Muhammad is His servant and messenger"

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Abstract

Over the last 50 years, social responsibility in the supply chain has changed from involving a single corporation to involving multiple companies. The empirical data show that social responsibility in the supply chain can be divided into five main streams: Purchasing Social Responsibility (PSR), Sustainable Transportation (ST), Sustainable Packaging (SP), Sustainable Warehousing (SW), and Reverse Logistics Social Responsibility (RLSR).

The aim of this thesis is to perform comprehensive modeling and analysis of integrated social responsibility in the supply chain for building sustainability. One of five main streams of integration are selected that is RLSR. RLSR is selected since it involves most of actors in supply chain who has an impact from social responsibility.

The aim of this thesis is achieved by three main issues. The first issue focuses on System Dynamics (SD) model building of RLSR based on interrelated sustainability dimensions. The second issue focuses on building efficient flexible capacity planning policy for RLSR to tackle product lifecycle with its inherited uncertainty for optimal interrelated sustainability dimensions' performance. The third issue focuses on the impact of product lifecycle disruption on the second issue model.

First, the challenge for involving as many actors in the supply chain for doing corporate social responsibility, has force the actors in supply chain to do RLSR. This force comes with difficulties ranging from multi-dimensional performance focus, to the short-long term sustainability orientation. Combines with the additional complexity of supply chain, it creates much more than a trivial exercise. Here, a simplified single-product system dynamics model consists of complex supply chain actors doing reverse logistics social responsibility, is developed. The market response due to premium price and environment performance are featured. Social contribution level and reverse logistics capacity planning policy are delivered as policy options with interrelated triple bottom line as performance measurement. The results show how corporate social responsibility produces economic, environment and social return through reverse logistics.

Second, product lifecycle uncertainties in Closed-Loop Supply Chains (CLSCs) are costly and frequently unavoidable. So the aim of this step is to develop efficient flexible long-term capacity planning policy for CLSCs that considers social responsibility or a supply chain with RLSR. This aim is to answer an important research question on how to tackle the lifecycle with its inherited uncertainty to achieve optimal sustainability dimensions performance. Here, a single-product SD model of the supply chain with RLSR is used. This SD model considers interrelated sustainability dimensions and adopts the product lifecycle with its inherited uncertainties, such as the length of the product lifecycle, pattern of the product lifecycle, and residence index. Finally, a mathematical model of the developed policy is constructed and a simplified non-linear multi-objective algorithm is proposed to solve this mathematical model. In addition, Taguchi Design is used to minimize the number of simulations needed in the numerical experiment. The findings of this study show that the developed policy could be used to tackle the lifecycle with its inherited uncertainty to optimize the sustainability dimensions performance. These findings have some limitations, however. the findings underscore this paper's contribution to the relatively limited but important academic knowledge on capacity planning development for research on social responsibility issues in CLSCs. In practice, the results will give managers a better understanding of how to tackle product lifecycle uncertainties in RLSR and will therefore lead to better capacity planning to achieve optimal sustainability dimensions performance.

Third, RLSR is preferred as a social responsibility activity in the supply chain since it involves most of the supply chain actors who have an impact on social responsibility. So here, a single-product SD model of the supply chain with RLSR is developed. The product lifecycle with its inherited uncertainties, such as the length of the product lifecycle, pattern of the product lifecycle, and residence index, is adopted by considering interrelated sustainability dimensions. Efficient flexible capacity planning is established as a policy option by considering a social responsibility fund from the premium price that is contributed by consumers. The Taguchi design of experiment is used for analysis of the numerical simulation. Finally, the significance with its power is measured to show the power of the relationship between policy and uncertainty for the sustainability dimensions' performance. These features will be used to analyze the impact of capacity planning on product lifecycle for performance on sustainability dimensions in RLSR by using an SD approach. The findings show that the policy parameters have an effect on any measured performances and uncertainties with some conditional exceptions. These findings reveal three interesting facts regarding RLSR due to the considered model features. First, the economic performance is a result of a direct influence of policy. Second, the environmental performance results from the indirect effect of the policy. Third, the social performance is the performance that is hardest to influence by policy. Therefore, the findings underscore this paper's contributions to the relatively limited academic knowledge on the examination of the impact of behavior in reverse logistics as a social responsibility due to capacity planning and the product lifecycle with its inherited uncertainties. These contributions offer managers a better understanding of the relationship between capacity planning, product lifecycle with its inherited uncertainties, and sustainability performance. This better understanding will lead to better capacity planning to tackle product lifecycle with its inherited uncertainties for sustainable RLSR.

Keywords: Sustainable Supply Chains, Reverse Logistics Social Responsibility, System Dynamics

Table of Contents

List of Figures

List of Tables

List of Functions

Chapter 1 Introduction

1.1 Background of study

The concept of social responsibility in this paper is proposed by looking at the company in the supply chain as an entity that is an organism. This concept is aligned with "the company as the real entity theory" for sustainability (Lozano, Carpenter, & Huisingh, 2014). As a real entity, the company has rights and responsibilities. The company has the right to produce and transport the product. But on the other hand, the company has a responsibility to overcome the impact on both the environment and society due to their rights activities. This mutualism between rights and responsibilities is applied not only to the company but also to the consumer (Caruana & Chatzidakis, 2013). The consumer has the right to consume the product, but the consumer has a responsibility for overcoming the impact on both environment and society due to his/her consumption activity; for example, the consumer is responsible for his/her used products. Then, put simply, on the companies' side, the social responsibility acts are called Corporate Social Responsibility (CSR). On the other hand, on the consumers' side, their social responsibility acts are called Consumer Social Responsibility (CnSR). That is another reason why RLSR is chosen in this paper, since RLSR could integrate CSR as the companies' social responsibility and CnSR as the consumers' social responsibility.

This concept of social responsibility has a close relationship with ISO 26000. There are seven core subjects in ISO 26000 (ISO, 2015). This paper's concept is related with four out of seven of these core subjects. First, the concept is related to core subject of 'organization'. The involvement of most actors in the supply chain including the consumer is the key reason for conducting RLSR, as stated in the Introduction. Second, the concept is related to core subject of 'environment'. The key activity in this paper is reverse logistics, which is reusing used products to conserve the environment by minimizing the amount of products disposed of. Third, the concept is related to core subject of 'fair operating practice'. Here both company and consumer are balancing their rights and responsibilities as real entities as stated in the previous paragraph. Last, the concept is related to core subject of 'consumer issues'. Here the consumer is carrying out his or her social responsibility (CnSR) by paying the premium price to support recycling activity and returning the used products to the collection facility. So there is consumer involvement here.

Even though the concept of social responsibility in this paper has a close relationship with ISO 26000, ISO 26000 is not considered here. This is because the social responsibility should adopt the uniqueness of local value where the company operates. So due to this local value adoption, ISO 26000 is not verifiable by a third-party certification, unlike ISO 9000 or ISO 14000 (Castka & Balzarova, 2008a, 2008b). This is why ISO 26000 is becoming a guideline for social responsibility rather than a quality standard of social responsibility (ISO, 2015).

In contrast, by looking at the company and consumer in the supply chain as the organism entities, no unique local value should be discussed in social responsibility. Now the focus of social responsibility should be only on the "mutualism", which represents the balance between the rights and the responsibilities of both company and consumer in the supply chain. Therefore, a sustainable supply chain could be achieved through social responsibility by maintaining this mutualism and focusing on sustainability dimensions performance such as the economic, environmental, and social performances. Now this relationship – the "mutualism" and sustainability dimensions –and the reason why ISO 26000 is not considered here – just as guidance – are clearly shown.

1.2 Research questions and aims

The aim of this thesis is to perform comprehensive modeling and analysis of integrated social responsibility in the supply chain for building sustainability. One of five main streams of integration are selected that is RLSR. RLSR is selected since it involves most of actors in supply chain who has an impact from social responsibility.

The aim of this thesis is achieved by three main issues. The first issue focuses on System Dynamics (SD) model building of RLSR based on interrelated sustainability dimensions. The second issue focuses on building efficient flexible capacity planning policy for RLSR to tackle product lifecycle with its inherited uncertainty for optimal interrelated sustainability dimensions' performance. The third issue focuses on the impact of product lifecycle disruption on the second issue model. The conceptual figure of these issues is shown in **Fig. 1** and the brief explanation of these four issues are described below.

First, the challenge for involving as many actors in the supply chain for doing corporate social responsibility, has force the actors in supply chain to do RLSR. This force comes with difficulties ranging from multi-dimensional performance focus, to the short-long term sustainability orientation. Combines with the additional complexity of supply chain, it creates much more than a trivial exercise. Here, a simplified single-product system dynamics model consists of complex supply chain actors doing reverse logistics social responsibility, is developed. The market response due to premium price and environment performance are featured. Social contribution level and reverse logistics capacity planning policy are delivered as policy options with interrelated triple bottom line as performance measurement. The results provide the answer for the following important research question "how corporate social responsibility produces economic, environment and social return through reverse logistics ?".

Second, product lifecycle uncertainties in Closed-Loop Supply Chains (CLSCs) are costly and frequently unavoidable. So the aim of this issue is to develop efficient flexible long-term capacity planning policy for CLSCs that considers social responsibility or a supply chain with RLSR. This aim is to answer an important research question on "how to tackle the lifecycle with its inherited uncertainty to achieve optimal sustainability dimensions performance".

Third, RLSR is preferred as a social responsibility activity in the supply chain since it involves most of the supply chain actors who have an impact on social responsibility. So here, a single-product SD model of the supply chain with RLSR is developed. The product lifecycle with its inherited uncertainties, such as the length of the product lifecycle, pattern of the product lifecycle, and residence index, is adopted by considering interrelated sustainability dimensions. Efficient flexible capacity planning is established as a policy option by considering a social responsibility fund from the premium price that is contributed by consumers. The Taguchi design (Georgiadis & Athanasiou, 2010) of experiment is used for analysis of the numerical simulation. Finally, the significance with its power is measured to show the power of the relationship between policy and uncertainty for the sustainability dimensions' performance. These features will be used to analyze on "how the impact of capacity planning on product lifecycle for performance on sustainability dimensions in RLSR happens".

1.3 The structure of the dissertation

The thesis consists of six chapters. The research topics are mainly distributing among the chapters as follows:

a. **Chapter 1** presents the introduction of social responsibility integration in supply chain, scope and objective, and thesis organization;

b. **Chapter 2** provides comprehensive review about one of five main streams of social responsibility in supply chain that is RLSR including its approaches and methods;
c. **Chapter 3** presents SD model building of RLSR by considering interrelated sustainability dimensions;
d. **Chapter 4** presents efficient flexible capacity planning policy model building for RLSR with product lifecycle;
e. **Chapter 5** presents the impact of product lifecycle on the supply chain with RLSR;
f. **Chapter 6** presents the conclusions and future direction of the thesis.

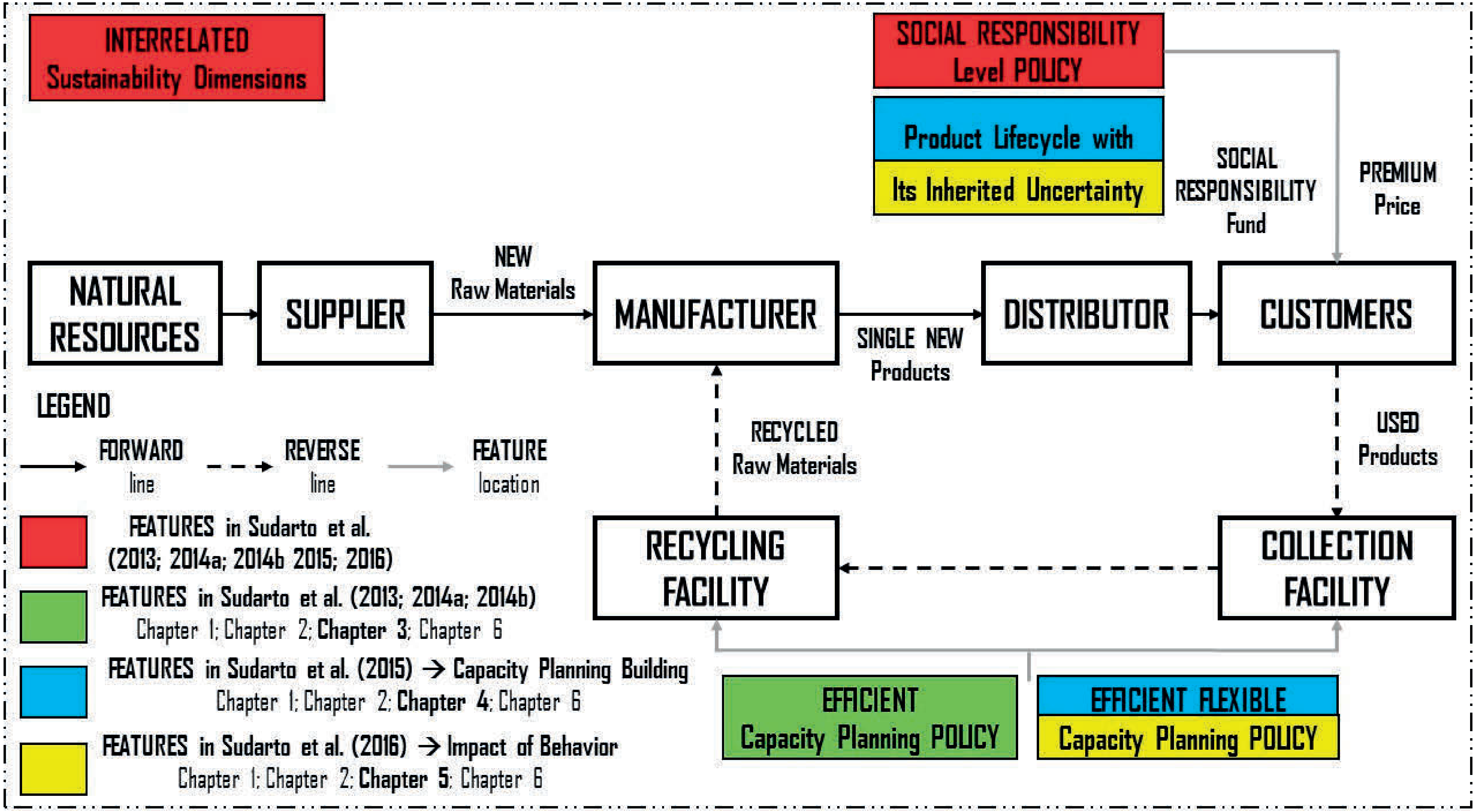

Fig. 1.1 The conceptual figure of research issue in this thesis

Chapter 2 Social Responsibility in Supply Chain

2.1 Social responsibility streams in supply chain

There are complex relationships between social responsibility, risk, and profit in the supply chain. First, the risk consists of supply-side disruption risk, social risk, and demand-side uncertainty. Second, profit refers to not only economic effects but also customer loyalty through reputation. Third, poor social responsibility performance by any player in the supply chain may damage the focal firm's reputation, such as in the cases of McDonalds, Mitsubishi, Monsanto, Nestlé, Nike, Shell, and Texaco. These relationships have the consequence that for some actors, social responsibility becomes a cost, while other actors earn social responsibility benefits. So, the actors need to work together to share the mutual risk and profit.

Accordingly, over the last 50 years, social responsibility in the supply chain has changed from involving a single corporation to involving multiple companies. The empirical data show that social responsibility in the supply chain can be divided into five main streams, namely:

a. Purchasing Social Responsibility (PSR), which is purchasing while considering social issues;
b. Sustainable Transportation (ST), which is carrying out transportation while preserving social justice now and for the future;
c. Sustainable Packaging (SP), which is packaging the product in such a way as to add value to society and environment;
d. Sustainable Warehousing (SW), which is warehousing while considering benefits to the local community;
e. Reverse Logistics Social Responsibility (RLSR), which is related to the reduction of resource use, recycling, substitution, reuse, and disposal of materials

Reverse Logistics Social Responsibility (RLSR) is preferred as the integrated social responsibility activity in supply chains (Sarkis, Helms, & Hervani, 2010; Sudarto, Takahashi, & Morikawa, 2014). RLSR is a type of Reverse Logistics (RL) that is conducted in the supply chain as a voluntary integrated social responsibility activity. RLSR involves most actors in the supply chain who have an impact on social responsibility (Ciliberti, Pontrandolfo, & Scozzi, 2008b). RLSR involves both companies and customers in the supply chain that need to perform social responsibility due to the impact of their activities, which influence both the environment and society (Caruana & Chatzidakis, 2013). In addition, involving as many actors as possible in the supply chain is critical since social responsibility performance among actors affects the other actors' performances (Cruz, 2013; Formentini & Taticchi, 2014).

Interrelated sustainability dimensions reveal a new drawback compared to classic sustainability dimensions (Seuring, Sarkis, Müller, & Rao, 2008a). According to the classic sustainability dimensions, sustainability is founded on three dimensions: economic, environmental, and social (Elkington, 1999). In early study, these three sustainability dimensions are independent of each other. Based on these classic sustainability dimensions, an earlier study of how RLSR could enable actors to achieve sustainability has been conducted (Nikolaou, Evangelinos, & Allan, 2013). In contrast to classic sustainability dimensions, the sustainability dimensions in interrelated sustainability dimensions are not independent but interact with each other. This feature reveals a new drawback: that by considering the trade-off among sustainability dimensions, the interrelated benefits and disadvantages of each sustainability dimension could be earned. So in relation to social responsibility in the supply chain, the interrelated sustainability dimensions could give a clear answer to the important question of how economic return could emerge from social responsibility activity (Ciliberti, Pontrandolfo, & Scozzi, 2008a).

2.2 The triple roles of customers in the supply chain with reverse logistics social responsibility

Establishing an effective and efficient system for any type of material flow in the supply chain with a focus on environmental and economic concerns is the main area of study of Closed-Loop Supply Chain (CLSC) design (Golroudbary & Zahraee, 2015). Forward logistics functions are critical activities in the supply chain loop. But to fully close the loop, the RL functions and activities are necessary. Attempts to manage both forward and reverse flows in a supply chain are studied in the context of a CLSC.

In RL, customers have dual roles, creating difficulties that do not exist in a forward supply chain (a supply chain without RL functions). The RL functions may be more difficult to manage due to the inexperience with RL functions of most companies. In RL, the material's or product's customers are usually the suppliers of the same materials and products. In short, the customers are not only buying the new products but also supplying the used products as the material/product input to the collection facility. This dual function of customers contributes to managerial complexity and uncertainty (Bai & Sarkis, 2013). Managing this complex dual relationship requires both procurement and marketing efforts to be managed jointly.

In contrast, in RLSR, customers play triple roles, creating more difficulties than in RL, which highlights the importance of considering transportation disruption in RLSR. Unlike in RL, RLSR requires the customers to play a third role. The third role is to support the existence of RLSR by paying a premium or higher price to provide a social responsibility fund to finance the RLSR (Hsueh & Chang, 2008). This third role leads to the consequence that some customers will not buy the product at a certain level of premium price. On the other hand, the customers who contribute by paying the premium price will provide a social responsibility fund for carrying out RLSR. This means that the RLSR is limited by the social responsibility fund. Meanwhile, the effect of the additional lead time due to transportation disruption creates higher demand uncertainty at the distributor and manufacturer levels (Kumar & Nigmatullin, 2011). So at the worst, the additional lead time could transform the customers' demand backlog into unsatisfied demand due to customers canceling their orders. In the end, the increase of unsatisfied demand could decrease the social responsibility fund. The other potential effect is that collateral disruption may occur in the collection facility, the recycling facility, or both, since the unsatisfied demand will have a strong effect on the volume of used products.

2.3 Capacity planning in reverse logistics social responsibility

There is a strong need to become efficient in RL (Vlachos, Georgiadis, & Iakovou, 2007). The RL industry is highly capital- and investment-intensive. RL is characterized by high capacity acquisition costs and long acquisition delays. So a capacity expansion decision in the collection facility and particularly in the recycling line is costly and largely irreversible. This leads to a requirement for capacity planning based on a periodic review approach and for rather conservative decisions regarding the magnitude of investment in capacity (Georgiadis, 2013). The combination of high investment and low profit margins forces senior managers to be very conservative about new investments in capacity expansion and reluctant to invest unless there is clear evidence of need and profitability. In such a business environment, the manufacturer makes decisions about whether or not to acquire new capacity in a certain equal time interval (where length equals the review period of capacity).

On the other hand, due to the risks in both RL and RLSR, it is necessary for RL to focus not only on efficiency but also on flexibility. This is because an effective way to manage uncertainty and variance in operational and organizational systems is by introducing greater flexibility. The framework of RL flexibility is separated into operational and strategic flexibilities (Bai & Sarkis, 2013). Operational flexibility includes a variety of dimensions such as product and volume flexibility across various RL operational functions. Strategic flexibility includes the network and organizational design of actors in the entire supply chain. Based on this flexibility's term, the capacity planning in RLSR belongs to the operational flexibility. So capacity planning in RL should focus not only on efficiency but also on flexibility, especially in RLSR, where the need for efficiency and flexibility is higher compared to RL (Sudarto, Takahashi, & Morikawa, 2015), because in RLSR there is limited funding and a risk of transportation disruption that could disrupt the critical triple roles of customers.

So Capacity planning in RLSR involves more complex issues compared to the capacity planning in RL. Capacity planning is important for both supply chains with RL and those with RLSR. Capacity planning significantly influences the overall performance of the supply chain (Sudarto et al., 2014; Vlachos et al., 2007). The capacity planning in RL shows that the combination of high investment and low profit margins force senior managers to be very conservative about new investments in capacity expansion and reluctant to invest unless there is clear evidence of need and profitability (Georgiadis, 2013). In contrast, the capacity planning in RLSR highlights not only the difficulties that exist in RL but also that the difficulty in deciding whether to expand and/or contract in capacity planning is now constrained by the existence of a social responsibility fund that is generated from the premium price that is contributed by customers (Hsueh & Chang, 2008; Sudarto et al., 2014).

Chapter 3 Reverse Logistics Social Responsibility

3.1 Introduction

There has been a growing importance of integration between Corporate Social Responsibility (CSR) in Supply Chain (SC) for building sustainability, which rises from two different perspectives. The first perspective argues about stakeholder's force (Baden, Harwood, & Woodward, 2009) and the other argues about social license for sustainability (Gilberthorpe & Banks, 2012). But in equilibrium, both perspectives agree that the actors in SC needs to work together to achieve integrated CSR-SC yet the barriers of integration (Baden et al., 2009) needs to be solved, such as: CSR' value for money doubt (Ciliberti et al., 2008a) and CSR' source of investment (Ni & Li, 2012).

Accordingly, in quest of the activity for integrating CSR-SC, somehow difficult and complicated since by definition, CSR itself has no standard both in academic and practical area (Gilberthorpe & Banks, 2012). So, it makes the scope of CSR activity itself becomes unclear. Nevertheless, there are two most acceptable definition of CSR adopted nowadays. First definition is delivered by the European Union (EU) which argues about environment and social aspects must be fulfilled by voluntary CSR (Ciliberti et al., 2008b). In contrast, the second definition itself is self-defined by the CSR actors (Baden et al., 2009). Here, the first definition is preferred to avoid green and social wash issues produced by the second definition. Then, CSR's definition should be related to its barriers of integration in SC. Therefore, the activity needs to concern and achieve the performance in dimensions of economic, environment and social return simultaneously. Thus, for achieving these three dimensions performance at once to obtain sustainability. The Triple Bottom Line (TBL) sustainability by Elkington (1999) is taken on. Here, interrelated TBL (i-TBL) is preferred instead of non-interrelated TBL for measuring policy performance effectiveness. Since it could advance the understanding of win-win and trade-off situation of the contribution on the relation between the three dimensions of sustainability (Seuring et al., 2008a).

Empirically, integrated CSR-SC for sustainability approach could be classified into five main streams (Ciliberti et al., 2008b). The Reverse Logistics Social Responsibility (RLSR) as one of the five main streams, is the most preferable due to RLSR could accommodate the involvement of many right impacted SC actors unlike the other stream (Nikolaou et al., 2013; Sarkis et al., 2010). Nevertheless, the previous research about RLSR based on TBL has been conducted by several researchers (Nikolaou et al., 2013; Sarkis et al., 2010). Yet, for the best of our knowledge, they failed to solve the CSR-SC integration barriers. As well, they use non interrelated TBL performance.

In this paper, the simplified single-product System Dynamics (SD) model of integrated CSR-SC based on i-TBL to achieve sustainability, is developed. The SD is preferable due to the complexity of the model and it's free of feedbacks. The model is developed for showing how economic, environment and social returns could be advanced from CSR through RLSR. By concerning market response due to the trade-off between premium price to provide CSR fund and environment performance for improving sales. As the policy options, the social contribution level and reverse logistics capacity planning policy are given. Also, this chapter fulfills one of the critical question about how to create sustainability beyond corporate boundaries (Seuring & Gold, 2013).

Section 3.2 literature reviews on streams in integrated CSR-SC and Section 3.3 the Enhanced Closed Loop Diagram (ECLD) of reverse logistic social responsibility. Then, Section 3.4 shows the experiment design and model validation and Section 3.5 shows results and discussion of the run experiments to show the findings. Finally, Section 3.6 shows the summary of this chapter.

3.2 Corporate social responsibility in supply chain

Over the last 50 years, CSR has been transformed from single corporate to multi corporates involvement or SC (Maloni & Brown, 2006). The empirical data show that CSR in SC could be divided into five main streams (Ciliberti et al., 2008b), such as:

a. Purchasing Social Responsibility (PSR) that is purchasing by considering social issues;
b. Sustainable Transportation (ST) that is transporting while preserving social justice now and for the future;
c. Sustainable Packaging (SP) that is packaging the product by adding value to the society and environment;
d. Sustainable Warehousing (SW) that is warehousing by considering local community benefits;
e. Reverse Logistics (RL) which related to source reduction, recycling, substitution, reuse, and disposal of materials.

Focusing in SC level, some actors earn CSR as a cost, but others earn CSR benefits (Cruz, 2013). So, the actors in SC need to work together in CSR to balance the cost with benefits that each actor earns. Consequently, the impact to SC performance of role playing by each CSR's impacted actors in SC must be carefully considered. The example of role playing consideration (Cruz, 2013; Georgiadis & Besiou, 2008), such as:

a. Supplier, resources social license;
b. Manufacturer, center of CSR's cost-benefit;
c. Distributor, promote CSR to end customer;
d. Customers, key of SC CSR's success;
e. And the legislator, legislation producer in SC.

Since the focus is gaining number of CSR' impacted actors involved, so combining CSR-SC streams is not preferred. Since it only increase the complexity of activity but not the number of actors, e.g. PSR is done by supplier-manufacturer (Carter & Jennings, 2002) which both actors already involved in RL. Thus, RL is preferred due to RL involves more CSR' impacted actors compare to the other streams. In addition, RL promotes recycling, reuse, resources conservation and addresses various aspects of social sustainability (Nikolaou et al., 2013; Sarkis et al., 2010).

Next, for seeking the CSR source of investment and showing its economic, environment and social return. The shifting perspective from CSR as money spending to CSR as money generator as an incentive for CSR's involvement, is needed. Even though previous findings show that CSR related to firm's reputation then continue to customer loyalty and ended by economic profit, it could be given as integration CSR-SC incentive (Hsueh, 2014). Nonetheless, it fails to show environmental and social returns. As well, its basic assumption that greater CSR cost will produce greater demand increase, will deliver obvious findings that CSR positively improve the economic performance.

At the other hand, many researchers agree that customer plays strategic key of CSR success. Consequently, customer must be joined the CSR by their Consumer Social Responsibility (CnSR) due to their consumption (Caruana & Chatzidakis, 2013). So, the barriers of unclear economic return of CSR (Ciliberti et al., 2008a) could be overcome by asking the customer for the premium price. Therefore, the premium price is the meeting point between CSR and CnSR. There will be a demand loss due to premium price causes some customers are having less social sensitive compare to the others. However, the source of investment to supporting CSR (Hsueh & Chang, 2008; Ni & Li, 2012) is now being answered. The next challenge is how to find acceptable demand loss then recover and improve the demand after the premium price is taken by doing RLSR. This is the most important issue considered in this chapter.

3.3 Enhanced closed loop diagram of reverse logistics social responsibility for sustainability

Closed Loop Diagram (CLD) is a part of SD model validation (Sterman, 2002) and building confidence in the model (Forrester & Senge, 1979). Different with CLD, Enhanced Closed Loop Diagram (ECLD) is a simplified form of CLD for showing only the most important loops in the model. **Fig. 3.1** shows our ECLD. It consists of three main loops, such as two B (Balance) loops and one R (Reinforcement) loop. The left B-loop represents how the Demand will be decreased as the CSR contribution is increased (Price hike to Premium_Price) then it causes Demand loss. This process will produce CSR_Fund that will be used for financing RLSR. This loop adapts mathematical model of Price hike limits the Demand (Hsueh & Chang, 2008), but it's improved by adding Demand recovery and improvement feature. It leads the model to reinforce the Demand after the RLSR activity that finance by CSR_Fund, is conducted then produce environment performance. It represents by the R-loop. Then, the bottom B-loop argues the incompliance to legislation that will hit the SC economic performance (Georgiadis & Besiou, 2008). Therefore, the policy maker should carefully consider their policy since there is a tradeoff between Demand loss and recovery to improvement process with the need to compile with Legislation standard with existence of penalty.

The model of Georgiadis and Besiou, 2008 is adopted since their model represents how RL capability compile with Legislation through internal motivation (Design for Environment or DfE) to avoid penalty. Besides the Collection_Capacity and Recycling_Capacity in their model is assumed to be static then environment performance will always be constant. As well, no social performance means no social to economic return could be advantaged. So, such limitations are overcome by dynamic capacity planning policy and social performance is taken on. On the other hand, the model of Vlachos et al., 2007 is also adopted since the actors involved is same as the CSR' impacted actors in SC and the actors doing the same activity that is RL. But since they do not concern about the source of fund to finance RL, so limitless capacity planning policy could be taken in their SD model. In addition, no social performance measured so social to economic return couldn't be examined. Therefore, this limitation is overcome by limiting the capacity planning policy with the existence of CSR_Fund.

Then, as mentioned in sections 1 and 2, the policy options in the model consist of (1) CSR contribution level policy and (2) capacity planning policy (Collection Capacity and Recycling Capacity). In this paper, the policy is being simplified, as follows:

a. CSR contribution policy is having three scenario, such as: 0% (No CSR), 20% (Low Price hike) and 30% (High Price hike).
b. Capacity planning policy is having three scenario, such as: 1 (Normal), 2 (Aggressive and Frequent) and 3 (Less Aggressive and Less Frequent).

According to the **Fig. 3.1**, the first policy refers to CSR POLICY RULE in the left B-loop and rest policy refers to REVERSE LOGISTICS CONTROL RULE.

The first policy is represented by CSR_Level constant in the SD model with dimensionless unit. CSR_Level refers to how much the Price will be hiked into Premium_Price. The range of policy value is set in between 0 to 1, 0 means there is no CSR in doing in SC so there is no price hike, and 1 means there is a RL social responsibility with 100% price hike. In the end, this policy will adjust Demand loss but SC start to provide CSR fund to finance RLSR activity.

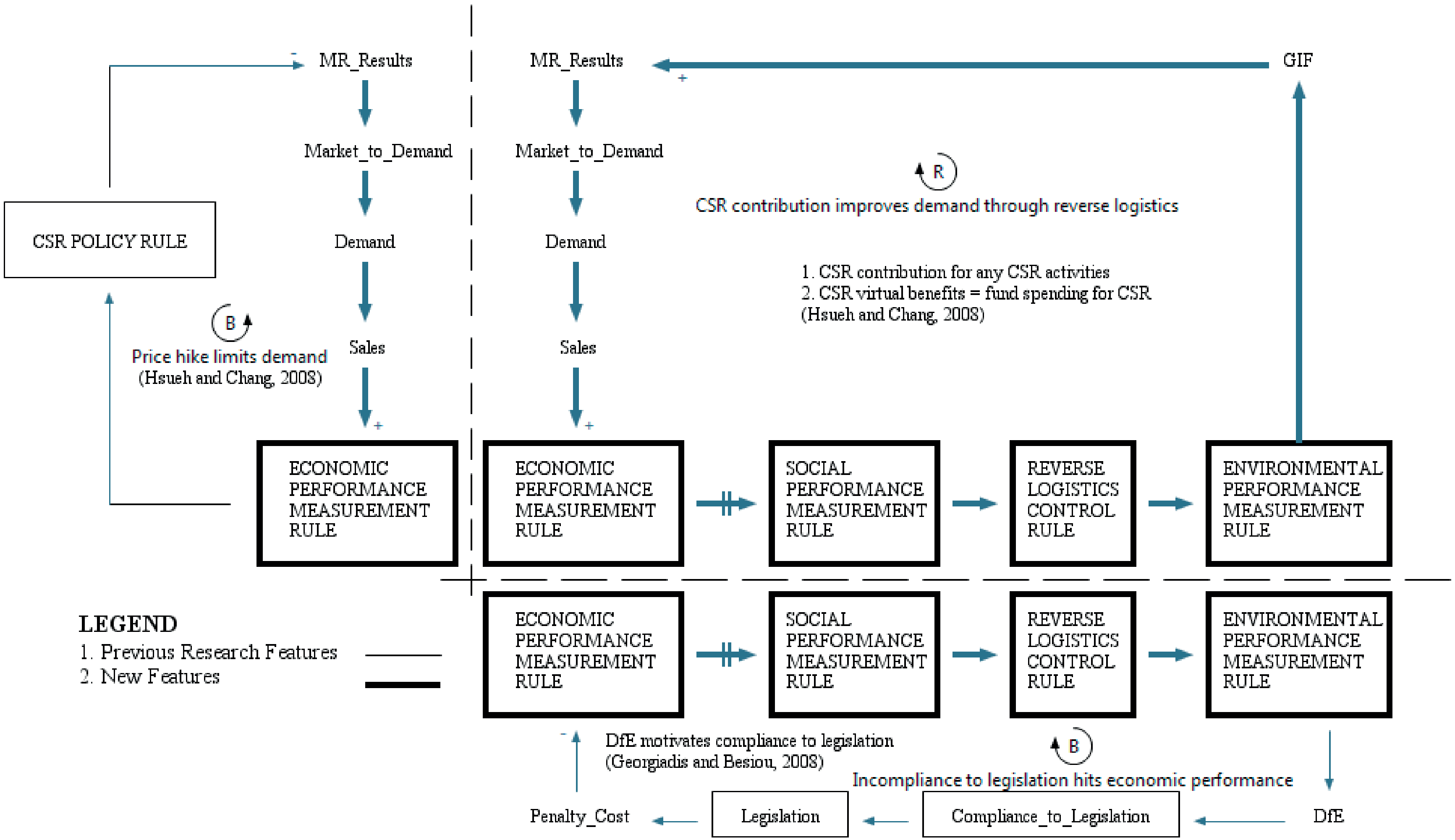

Fig. 3.1 Enhanced closed loop diagram of reverse logistics social responsibility for building sustainability

Differ with the first policy that used to adjust Price to earn CSR_Fund for achieving optimal economic and social performance results, the other policy is used to adjust RLSR capacity planning for optimal usage of CSR_Fund to obtain optimal environment performance. The Collection_Capacity planning policy is represented by Pc and Kc in the SD model with week for Pc unit and dimensionless for Kc unit. Pc represents the length of review period for Collection_Capacity with range of policy from 10 to 250, 10 refers to frequent review and 250 for less frequent review. Then, Kc represents control variable of Collection_Capacity with range of policy from 0.5 to 3.0, 0.5 refers to less aggressive capacity expansion, and 3.0 for aggressive capacity expansion. In the end, this policy will adjust the actual number of Collection_Capacity. The Recycling_Capacity planning policy has the same structure of second policy, but it assigns for Recycling_Capacity building and it represents by Pr and Kr. Both of the policy are adopted from Vlachos et al., 2007, then revised to align with first policy, the some details could be found in **Appendix A**.

Last, the SD model will be run for simulation and i-TBL performance measurement is used here for policy effectiveness with the relationship between performances dimensions are well shown in **Fig. 3.1**. Here, the term policy effectiveness refers to i-TBL performance in the following conditions, such as: (1) the value of each i-TBL performance dimensions (2) the value balance between each i-TBL performance dimensions. First, the economic performance will be measured. Second, the social performance based on economic return from RL activity will be measured. The last, environment performance will be measured as the results of RL activity. The detail information of measured TBL performance are given as follows:

a. Economic Performance

   It is represented by Total_Supply_Chain_Profit variable, which is defined as net present value of total SC profit with the Euro as the unit. The equation is assigned as "npv (Total_Profit_per_Period, Discount_Factor, 0, 1, 0.01)". The range of value is from $-\infty$ to $+\infty$.

b. Environment Performance

   It represents by GIF variable, which defined as Green Image Factor produced by RLSR activity with dimensionless as the unit. The equation is assigned as "GIF_Graph_1 (Reuse_Index)×MARKET_BEHAVIOR.get (1) + GIF_Graph_2 (Reuse_Index) × MARKET_BEHAVIOR.get (2) + GIF_Graph_3 (Reuse_Index)× MARKET_BEHAVIOR.get (3) + GIF_Graph_4 (Reuse_Index)× MARKET_BEHAVIOR.get (4)". It comes from collective result of four different type customers based on their social sensitivity. The range of value is from -0.15 to +0.15.

c. Social Performance

   It represents by Social_Performance variable, which defined as social performance based on CSR activity by considering economic return and CSR_Fund optimal usage. The (Euro/Week)/Week is the unit with "CSR_Fund == 0? 0: Total_Profit_per_Period×(CSR_Spending_Rate/CSR_Fund)" as the function. Here, in this formulation, the relationship of CSR to economic performance is clearly shown (Ciliberti et al., 2008a). Also, the fraction CSR_Fund to its spending is measured since the CSR virtual benefits could be assumed as same as the amount of money spent for CSR activity (Hsueh & Chang, 2008). The range of value is from $-\infty$ to $+\infty$. The negative means the CSR activity produce economic loss and vis-a-vis.

3.4 Experiment design

The experiment is design as shown in **Fig. 3.2**. The aim is to examine the economic, environment and social returns due to RLSR. As well, it proposes how to optimize i-TBL performance by given set of policy. The first aim is to validate the model. The question is "Is it the model already has the right internal relationship and behavior or not?". In this step, before the model is validated, the basic scenario is defined with arrays settings as shown in **Appendix A** with 300 weeks as simulation period. The simulation is design with week as unit for period and Euro for unit of currency. The data is quoted from previous related simulation research (Georgiadis & Besiou, 2008; Vlachos et al., 2007), but the other data for the novelty features with its supporting entities are hypothetically generated. Here, Anylogic 6.9.0 is used as simulation software and Minitab 17 is used as results analysis software.

Hereafter, the model is validated by using direct-structure test, structure-oriented behavior test and behavior-pattern test in sequence to confirm its validation and building model confidence (Barlas, 1996; Forrester & Senge, 1979). Then, after the model validation is confirmed, the second step is conducted. The second step is the policy scenario testing. The question is "How is the i-TBL performance behavior due to the implementation of policy scenario?". In this step, three different levels are CSR_Level are proposed to investigate the Price hike impact to TBL performance. In combining with the capacity planning policy that will be assigned to obtain optimal i-TBL performance by considering strategy for allocating CSR fund. In this step, while Collection_Capacity planning policy with its given CSR_Level are simulated, the other arrays setting in the model are set as shown in **Appendix A** and it's applied continuously until all possible policy range are simulated. The results from this step will be analyzed by manipulating them into surface chart (third step). Therefore, it's easier for us to study the behavior impact of policy scenario to the performance. Then its findings will be discussed with some supporting facts are provided.

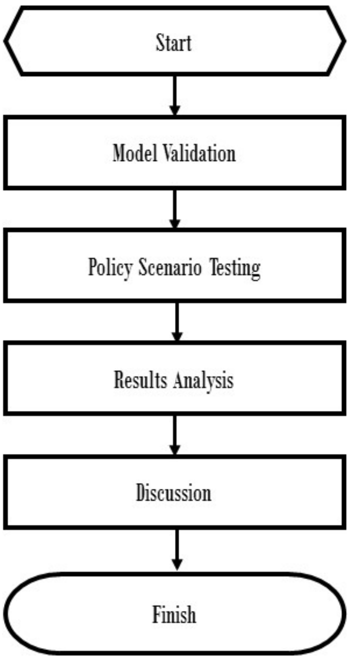

Fig. 3.2 Simulation experiment flow diagram

3.5 Results and discussions

The first step of experiment is the validation for SD model. The direct-structure test consists of theoretical structure-confirmation and parameter-confirmation test that refer to (Georgiadis & Besiou, 2008; Vlachos et al., 2007) then ended by dimensional consistency test by using Anylogic software's feature. From Anylogic test, no dimensional inconsistency and error have been found. Then it could be continued to the next step, that's structure-oriented behavior test that refers to extreme-condition test. In this step, all level type entities initial inventory are set to be 0 with no legislation and Initial_Non_Renewable_Materials is set to be 0. Then after the simulation, it produces such as: no Procurement, no Production, no Shipment, no Delivery, no Sales with no Collection_Capacity and no Recycling_Capacity has been build. Then, the measured i-TBL performance produces zero value performance. The last is behavior-pattern test, in this case the CSR_Level is set to 0.2 then the simulation is run. Two variables behavior are checked with previous research behavior. The results of simulation are shown in **Fig. 3.3** for the Collection_Percentage and Recycling_Percentage behavior. **Fig. 3.3** has been success matched its behavior to the previous research.

Next, the results of simulation then analysis through surface chart are shown in **Fig. 3.4** to **3.6**. From **Fig. 3.4,** the economic performance produce concave curve with the extreme value is around 0.2 CSR contribution level. In the other hand, the capacity planning policy produce curve that is more dynamic. If both of the policy are combined, the optimal results will be around 0.2 for CSR contribution level and between 2 to 3 for the capacity planning policy.

From **Fig. 3.5**, the in contrast to the results in **Fig. 3.4** happens. The environment performance shows concave curve with the extreme value around 2 for capacity planning policy. On the other hand, the CSR contribution level policy produce more dynamic curve. If both of the policy are combined, the optimal results will be in 0.2 and 0.3 for CSR contribution level and around 2 for the capacity planning policy.

From **Fig. 3.6**, the other interesting behavior happens. The social performance shows concave curve with the extreme value around 2 for capacity planning policy. In similar, the CSR contribution level policy is around 0.2. If both of the policy are combined, the optimal results will be in 0.2 for CSR contribution level and around 2 for the capacity planning policy.

From **Fig. 3.4** to **3.6**, the optimal policy for balancing the performance between economic, environment and social will be 0.2 for CSR contribution level policy and between 2 and 3 for capacity planning policy. This remark findings, have been significantly different by findings with the previous research (Vlachos et al., 2007). They argue that aggressive and frequent policy both in collection and recycling capacity planning policy could emerge a better economic performance. But in our findings, that is not always right, moreover by concerning the other performance dimensions, such as: environment and social. The policy makers, now have their wider policy option for selecting an appropriate policy for their own expected i-TBL performance dimensions. This findings are supported by facts shown in **Fig. 3.7** and **3.8** that refer to our model have limited fund for financing RL due to the existence of CSR_Fund. In contrast, Vlachos model considers limitless source of fund to finance RL. Therefore, the availability of CSR_Fund and the different condition of Sales after Price hike that in the end produce different Used_Products condition, limit the policy maker who used our model to conduct aggressive and frequent capacity planning policy in RLSR.

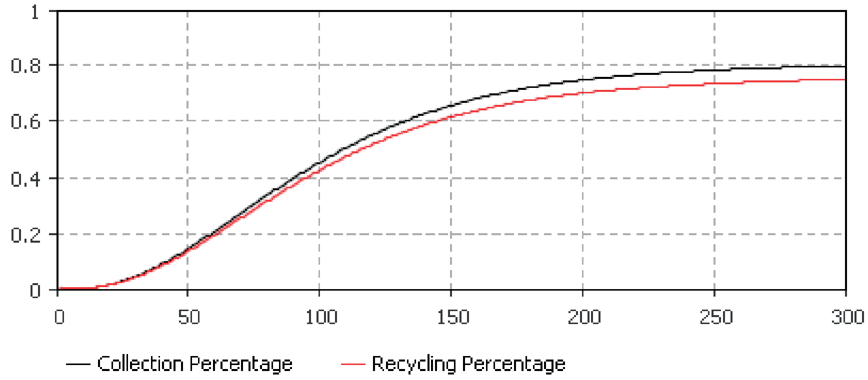

Fig. 3.3 Collection_Percentage and Recycling_Percentage behavior (Refers to **Fig. 12** in (Georgiadis & Besiou, 2008))

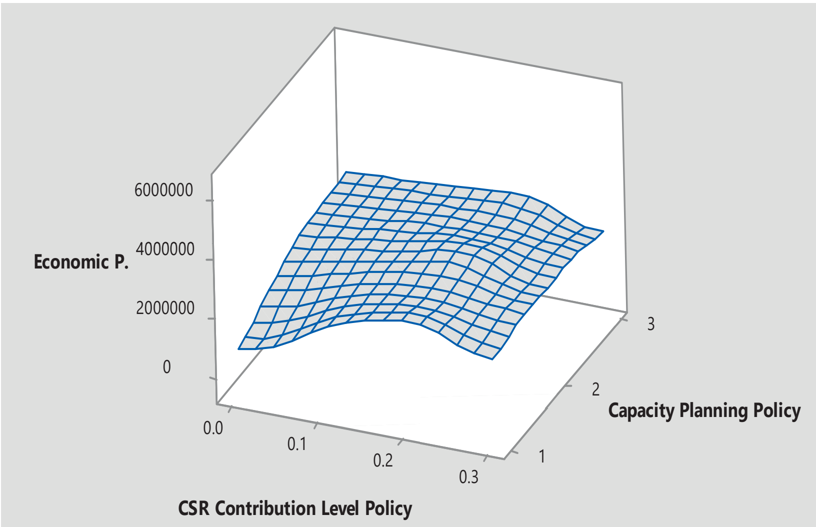

Fig. 3.4 Economic performance vs. policy's scenario

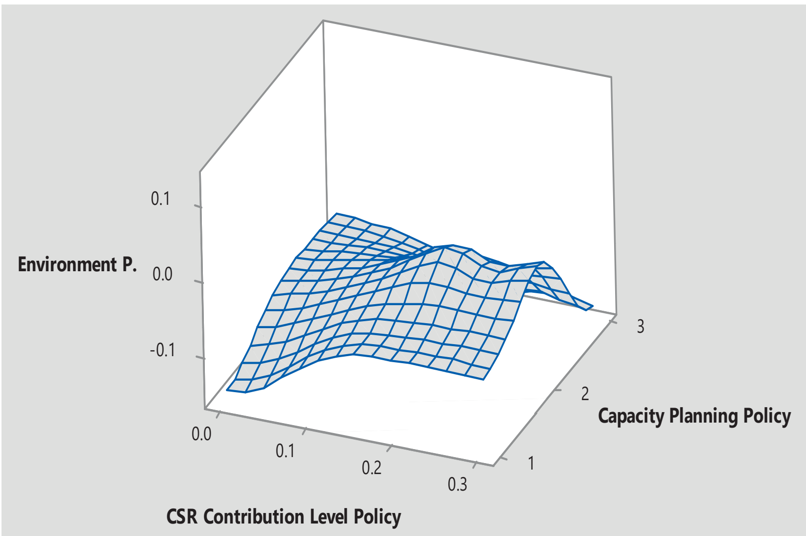

Fig. 3.5 Environment performance vs. policy's scenario

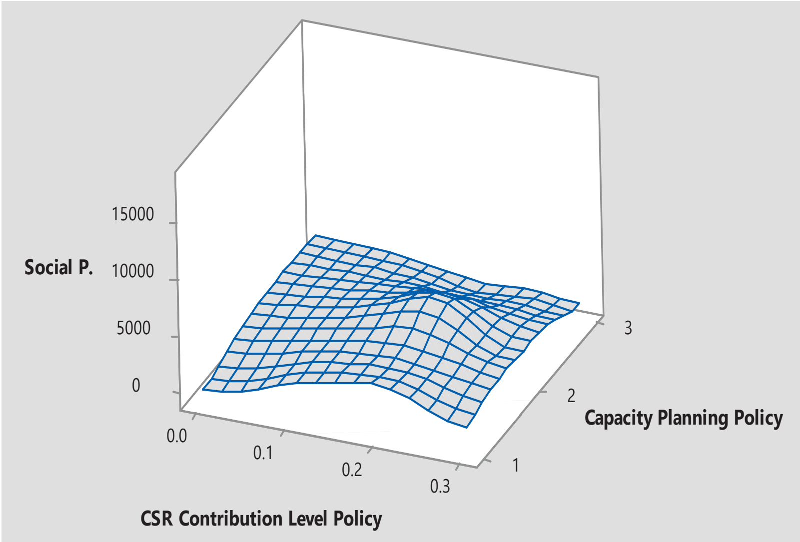

Fig. 3.6 Social performance vs. policy's scenario

In looking for the reason for such optimal policy and performance applied in **Fig. 3.4** to **3.6**. The supporting facts are needed to explain the behavior produce by the model. Then, the performance of critical variables are examined from any random possible optimal combination of policy. The critical variable consists of Sales, Reusable_Products, Collection_Capacity and Recycling_Capacity. The behaviors of such critical variables are shown in time series graph in **Fig. 3.7**. From this figure, the number of Sales and Collection_Capacity for low CSR contribution are greater compare to the higher value of CSR contribution. On the other hand, surprisingly the recycling facility has the less different amount of Reusable_Products inventory to be recycled. This condition deliver the Recycling_Capacity in both policy almost the same. All these conditions, cumulatively produce the performance shown in **Fig. 3.8**. Contradict with the end of simulation results in **Fig. 3.4** to **3.6**, **Fig. 3.8** shows the result in times series order. This figure reveals untold story compared to **Fig. 3.4** to **3.6**, that is for around first 30 weeks of simulation period, both economic and environmental performance of high CSR contribution is higher than the low, but produce equal social performance. In addition, this figure discovers that high CSR contribution level promising better i-TBL performance compared to the higher value of CSR contribution. However, this condition only could make a stand for the first short period of simulation.

3.6 Summary

A simplified SD model of RLSR to show how CSR produces economic, environment and social returns through RLSR, is constructed. The model considers the trade-off between market response and environmental performance through premium price. The numerical experiment, it's found that CSR could produce both TBL performance enhancement and digressions. The model greatly contributes on how CSR could emerge not only economic, but also environment and social returns through RLSR to reduce CSR' trivial risk and achieving sustainability. The future works should give priority to (1) find the others way to integrate CSR in supply chain and (2) proposes an empirical research to support the findings in this chapter.

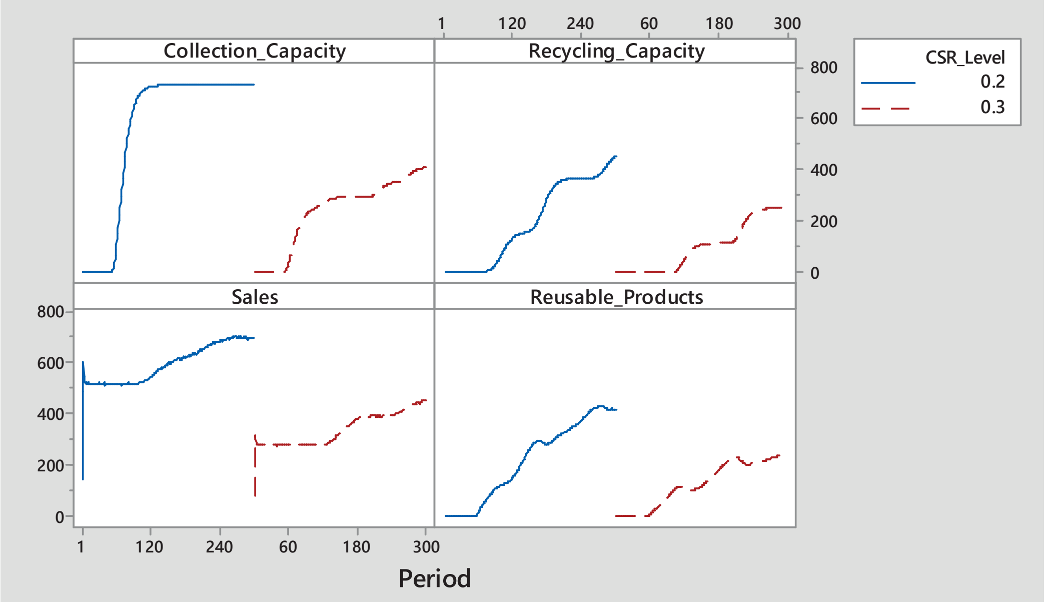

Fig. 3.7 Time series graph of supporting findings fact – monitored entities

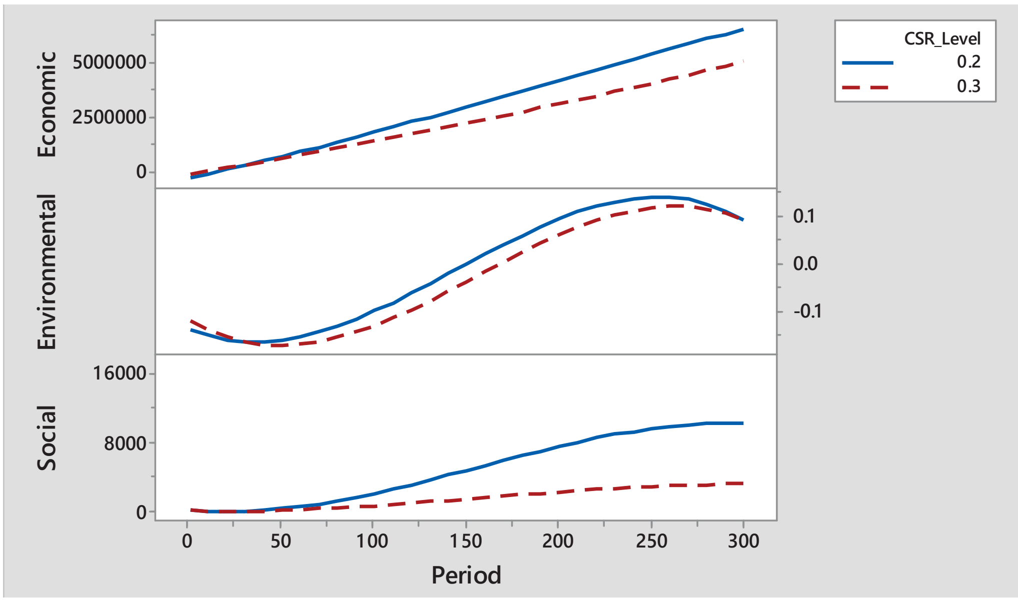

Fig. 3.8 Time series graph of supporting findings fact – i-TBL performance

Chapter 4 Efficient Flexible Capacity Planning

4.1 Introduction

This chapter proposes a concept of social responsibility by considering both company and consumer in the supply chain as entities that are organisms (Caruana & Chatzidakis, 2013; Lozano et al., 2014). This concept has a close relationship with ISO 26000 (Castka & Balzarova, 2008a; ISO, 2015). But unlike ISO 26000, here the social responsibility focuses on "mutualism", which represents the balance between the rights and responsibilities of both companies and consumer in the supply chain for sustainability.

Reverse Logistics Social Responsibility (RLSR) is preferred as the integrated social responsibility activity in supply chains (Sarkis et al., 2010; Sudarto et al., 2014). RLSR is a type of Reverse Logistics (RL) that is conducted in the supply chain as a voluntary integrated social responsibility activity. RLSR involves most actors in the supply chain who have an impact on social responsibility (Ciliberti et al., 2008b). RLSR involves both companies and customers in the supply chain, who need to perform social responsibility due to the impact of their activities, which influence both the environment and society (Caruana & Chatzidakis, 2013). In addition, involving as many actors as possible in the supply chain is critical since social responsibility performance among actors affects the other actors' performances (Cruz, 2013; Formentini & Taticchi, 2014).

Interrelated sustainability dimensions reveal a new drawback compared to classic sustainability dimensions (Seuring et al., 2008a). In contrast to classic sustainability dimensions (Elkington, 1999), the interrelated sustainability dimensions (economic, environmental, and social) are not independent but interact with each other. This feature reveals a new advantage: that by considering the trade-off among sustainability dimensions, the interrelated benefits and disadvantages of each sustainability dimension could be earned. So in relation to social responsibility in the supply chain, the interrelated sustainability dimensions could give a clear answer to the important question of how economic return could emerge from social responsibility activity (Ciliberti et al., 2008a).

Capacity planning in RL, regarding expansion and contraction of collection and recycling capacities, involves complex issues (Georgiadis & Athanasiou, 2010). The uncertainty inherited from the RL due to the variability of a product's usage period, along with the unknown reusability, the breakdown rate, and the recycling rate of the used products, makes the decision-making process about the capacity policies a difficult task to accomplish. This uncertainty entails a higher risk of shortage of end-of-use product returns, since supply may vary and the dismantling volume may turn out to be lower than predicted. This will cause the overcapacity phenomenon in capacity planning, which, in the long run, may negatively affect the profitability, especially in high capacity acquisition conditions (Georgiadis & Athanasiou, 2013). So there is a close relationship between complex issues in the capacity planning and product lifecycle; for example, the case of Pack2-pack shows that capacity planning in the reverse channel of Closed-Loop Supply Chains (CLSCs) can impact the lifecycle of product families produced in the forward channel.

The decision to expand or contract capacity is associated with important questions that need to be answered, such as when, where, and how much to expand/contract. However, the capacity planning in RLSR is more complex than that in common RL. As RL is a social responsibility activity, the decision to either expand or contract is now constrained by the existence of a social responsibility fund that is generated from the premium price borne by the consumers (Hsueh & Chang, 2008; Sudarto et al., 2014). Moreover, in RLSR it is necessary to consider the interrelated sustainability dimensions that affect not only the economic but also the environmental and social performance. Therefore, the capacity planning in RLSR becomes much more than a trivial exercise.

The aim of this chapter is to develop efficient flexible long-term capacity planning policy for RLSR by using the system dynamics (SD) approach. The model is single-product. **Fig. 4.1** shows the flow diagram of the methods used in this chapter. The SD approach is used since the supply chain under this study is complex and the system under study is dynamic and limited by feedback. So, SD is preferred compared to optimization to avoid the occurrence of infeasible solutions (Hsueh, 2014). The term "efficient" refers to the allocation of a limited social responsibility fund (Sudarto et al. 2014), while the term "flexible" refers to the adaptability (Bai and Sarkis 2013; Georgiadis and Athanasiou 2013) to tackle the lifecycle with its inherited uncertainty. So, the efficient flexible capacity accommodates the need to become adaptable to uncertainty with a limited social responsibility fund. Here, the developed capacity planning policy works together with the social responsibility level policy (Hsueh & Chang, 2008). The considered inherited uncertainties include the product Lifecycle length (L), its return Patterns (P), and the Residence Index (RI) (Georgiadis et al. 2006). Last, the interrelated sustainability dimensions' performance is measured to find out the policy impacts. This part of study will answer the important question of how to tackle the lifecycle with its inherited uncertainty for optimal sustainability dimensions performance. In addition, the Taguchi design of experiment is used (Antony, 2003; Ramachandran & Tsokos, 2015) to minimize the number of simulations needed in the numerical experiment. One good example of a real-world practice that is comparable to the social responsibility concept in this chapter is the automotive-related recycling law in Japan issued by the Japanese Ministry of the Environment (http://www.env.go.jp/en/laws/recycle/).

The chapter is structured into the following sections. The first section presents the introduction. The second section discusses the seminal works in capacity planning for RL and RLSR which are contrasted with this chapter's original contributions. The third section discusses the efficient flexible long-term capacity planning, and the fourth section discusses the experimental design. The fifth section presents the results and discussion. Last, the conclusions and possible future extension of the research will be discussed in the sixth section.

4.2 Capacity planning in reverse logistics and reverse logistics social responsibility

This literature review section is divided into two parts. First, a brief overview of social responsibility in supply chains is discussed. Second, the capacity planning for RL and RLSR is discussed to show the merits of the proposed efficient flexible long-term capacity planning. So, the relationship between the proposed capacity planning and its merits for social responsibility in the supply chain is clearly shown.

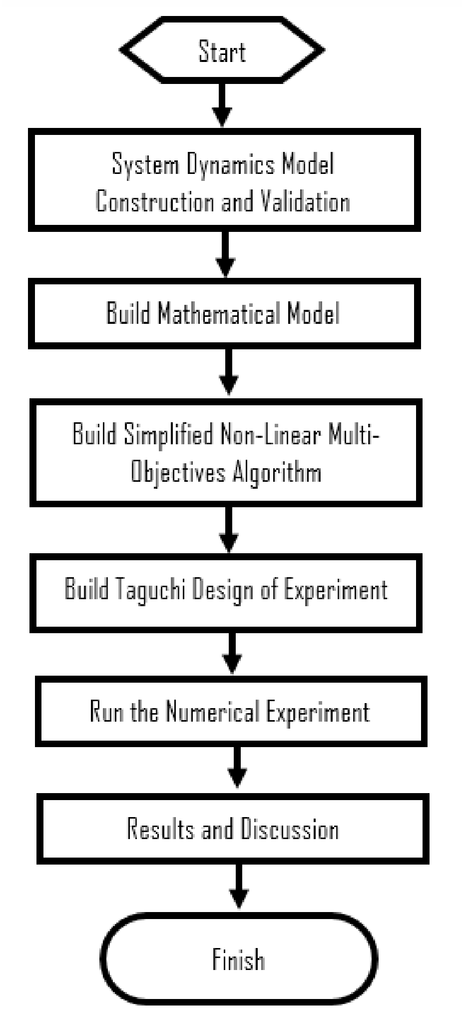

Fig. 4.1 Flow diagram of methods

4.2.1 Social responsibility in the supply chain

Poor social responsibility performance of any player in the supply chain may damage the reputation of the corporation at the center of focus, such as in the cases of McDonalds, Mitsubishi, Monsanto, Nestlé, Nike, Shell, and Texaco (Cruz, 2013). Therefore, actors need to work together to perform social responsibility. Unlike the classical social responsibility perspective, which is "charity" oriented, the newer perspective claims that social responsibility is an incentive for actors in the supply chain to act together to create additional revenue and benefits (Caruana & Chatzidakis, 2013). Besides, the newer perspective can only exist by involving consumers in the supply chain as the key to social responsibility. The different motivations among corporations and consumers in the supply chain for performing social responsibility are that the corporation consumes resources to produce and transport products whereas the consumer is responsible because of he or she consumes the products, which could damage the environment, society, or both after their consumption period (Hsueh, 2014).

Over the last 50 years, social responsibility in the supply chain has been transformed from single-corporation to multi-corporation involvement (Maloni & Brown, 2006). The empirical data show that social responsibility in the supply chain can be divided into five main streams (Ciliberti et al., 2008b); one of them is RLSR, which is related to source reduction, recycling, substitution, reuse, and disposal of materials.

Since the actors in the supply chain need to work together to balance the share of risk and profit, the impact on the supply chain performance of the role played by each social-responsibility-impacted actor in the supply chain must be carefully considered. Examples of roles played include (Cruz, 2013; Georgiadis & Besiou, 2008) the supplier as the resources social license holder; the manufacturer as the center of social responsibility cost–benefit receiver; the distributor as the promoter of social responsibility to the end customer; customers as the key to the success of the supply chain social responsibility; and legislators as the producers of social responsibility legislation. Because the focus is on gaining the involvement of a number of social-responsibility-impacted actors, it is not preferable to combine any streams, since this would increase the complexity of the activity but not the number of actors; for example, Purchasing Social Responsibility is done by the supplier-manufacturer (Carter & Jennings, 2002), where both actors are already involved in RLSR. Thus, RLSR is preferred because it involves a greater number of impacted actors compared to the other streams.

A comparison of the RLSR SD model features under this study and in previous research is presented in **Table 4.1**. The number of research articles on social responsibility issues is relatively limited (Govindan, Soleimani, & Kannan, 2014; Hsueh, 2015), especially in CLSCs. Therefore, the selected papers in **Table 4.1** for selecting the benchmark model in this chapter are based on the research articles most similar to the research in this chapter that, to the best of the authors' knowledge, can be found. As shown in **Table 4.1,** except for Hsueh and Chang (2008), the benchmark models have at least two fundamental similarities. First, the benchmark models have CLSC networks that produce as-good-as-new products. Second, they consist of collection and recycling operations in the reverse channel. From this table, it can be seen that the SD model features used are closely related to those of in Chapter 3, with significance differences with regard to product lifecycle, trade-off, and policy.

Hsueh and Chang (2008) propose a mathematical model of the relationship between social contribution levels in the supply chain that affects the total supply chain profit**.** Their merits about the social responsibility fund that comes from the premium price that is borne by the consumer delivers one of many possible answers on where the money for performing social responsibility should come from and how the corporation–consumer social responsibility should be met. The fund is strongly related to the trade-off between sales loss due to price increase and sales increase from reputation gained due to social responsibility activity. They also argue that the "virtual social responsibility benefits", for example, social license, good reputation, and so on, could be assumed to be equivalent to the money spent on social responsibility. However, they are not measuring the social performance in their research. Here, their merit is limited because they fail to answer important questions on where the money in social responsibility fund should be invested and how the social responsibility reputation that will increase sales is gained. These limitations are overcome by Sudarto et al. (2014).

Sudarto et al. (2014) proposed that the fund should be invested in RLSR to balance the share of risk and profit of social responsibility. They use the SD model from Vlachos et al. (2007) and Georgiadis and Besiou (2008) as the basis model. So, the green image that drives the increase in demand could emerge from the invested fund. Also, they measure the social performance as a ratio of the invested fund to the economic loss or gain. This is the reason why the SD model features considered in this study, such as the social responsibility fund, sales loss, and social contribution levels policy, are taken from Sudarto et al. (2014). However, unlike their features, the SD model used here proposes a cumulative change of green image as the environmental performance and the net present value of social benefits as the social performance to allow cooperation with product lifecycle issues. Since the social responsibility fund and sales are strongly related to the product lifecycle, the performance of one product lifecycle could be considerably advanced and the improvement of the developed efficient flexible capacity planning in this chapter could be measured. In addition, this is also the reason why a single-product model is preferred rather than a multi-product model as in Georgiadis and Athanasiou (2013).

There is a need to consider economic, environmental, and social performances in RLSR or supply chains with social responsibility. The need highlights the issue of social responsibility in the supply chain, which has a complicated definition. Since social responsibility itself has no standard definition in either academia or practical areas (Gilberthorpe & Banks, 2012), the definition adopted by the European Union (EU), which argues that environmental and social needs must be fulfilled by voluntary social responsibility (Ciliberti et al., 2008b), is preferred to avoid green-washing issues produced by the other definition (Baden et al., 2009). Therefore, social responsibility needs to consider and achieve performance on economic, environmental, and social dimensions simultaneously.

Put simplify, the SD model used is an extension of the RLSR SD model of Sudarto et al. (2014) and also includes some improvements from Georgiadis et al. (2006) with regard to the product lifecycle with inherited uncertainty features (similar to Georgiadis and Athanasiou 2010) and from Georgiadis and Athanasiou (2013) with regard to flexibility features in capacity planning. So this chapter will contribute to the relatively limited but important academic knowledge on capacity planning development for RLSR (Govindan et al., 2014; Hsueh, 2015) in order to improve/offer efficiency and flexibility. In addition, even though the capacity planning in Georgiadis's model (2013) is very similar to the capacity planning proposed here, his model focuses only on profit, rather than considering the full product lifecycle, and is developed under ordinary RL systems, not RLSR.

4.2.2 Capacity planning in reverse logistics and reverse logistics social responsibility

Since, by definition, social responsibility is driven by voluntary motivation, here the RLSR model adopts the ecological motivation feature. This feature is taken from Chapter 3 in order to see how voluntary motivation drives collection and recycling activity. Their feature is also adopted by Georgiadis and Besiou (2008).

Table 4.1 Comparison of features in research on reverse logistics and reverse logistics social responsibility

References	Approach	Focus	Sustainable Dimensions			Lifecycle	Product(s)	Trade-off	Policy
			Eco.	Env.	Soc.				
Georgiadis et al. 2006	SD	Impact of behavior	√	-	-	Full	Single	Lifecycle; Patterns	Early stage CP
Vlachos et al., 2007	SD	Develop efficient CP	√	-	-	Limited	Single	Ecological motivation	Efficient CP
Georgiadis & Besiou 2008	SD	Impact of behavior	√	√	-	Limited	Single	Ecological motivation; Technological motivations	-
Hsueh & Chang 2008	OR	Social to economic mathematical model	√	-	√	Not considered	Single	Social responsibility fund; Sales loss	Social responsibility contribution level
Georgiadis 2013	SD	Develop efficient flexible CP	√	-	-	Limited	Single	Profit; Capacity utilization	Efficient flexible CP
Georgiadis & Athanasiou 2013	SD	Develop flexible CP	√	-	-	Full	Multi	Lifecycle; Patterns; Residence index; Quality level of used products	Flexible CP
Chapter 3	SD	Sustainable RLSR SD model	√	√	√	Limited	Single	Social responsibility fund; Sales loss; Ecological motivation	Social responsibility contribution level and efficient CP
Proposed model	SD	Develop efficient flexible CP	√	√	√	Full	Single	Social responsibility fund; Sales loss; Ecological motivation; Lifecycle; Patterns; Residence index;	Social responsibility contribution level and efficient flexible CP

Abbreviations: CP = Capacity Planning; OR = Operations Research; RLSR = Reverse Logistics Social Responsibility; SD = System Dynamics

Here, the flexible RL capacity planning feature from Georgiadis and Athanasiou (2013) is modified and then adopted. Unlike their model, here the efficient flexible capacity planning policy is proposed, since the RLSR activity in this study is limited by the social responsibility fund. Therefore, instead of becoming flexible in capacity planning like their model, the system in this study also needs to become efficient in allocating the fund. Here, the term efficient in capacity planning is adopted from Chapter 3 in order to consider not only the proportionality of capacity planning but also the review period, similarly to the work of Vlachos et al. (2007). This method will produce economies of scale of capacity expansion, which will emerge the optimal allocation of the social responsibility fund. However, unlike both of them (Chapter 3; Vlachos et al. 2007), the capacity planning proposed here accommodates not only capacity expansion but also capacity contraction, since the model under this study adopts a total demand pattern that refers to the product lifecycle.

The comparison of features between the proposed capacity planning and previous research is shown in **Table 4.2**. Georgiadis et al. (2006) proposed early stage capacity planning for RL. They use proportionality decision variables to produce economies of scale for capacity planning. The advantage of considering a full product lifecycle that includes expansion and contraction of capacity planning is that a powerful adaptability to uncertainty emerges during the lifecycle of the product. However, since there is a huge capacity expansion in the first stage of the product lifecycle, the initial investment needed for the RL is large. This large initial investment cannot be fulfilled by RLSR.

Unlike Georgiadis et al. (2006), Vlachos et al. (2007) proposed efficient capacity planning. Their merit in considering the review period has produced a small initial investment for reverse logistics. However, the use of the review period leads to the consequence that the adaptability to lifecycle uncertainty becomes less powerful. Additionally, since they do not consider the full product lifecycle, their capacity planning only designs expansion activity but does not include contraction activity. This limitation of the absence of contraction is overcome by the proposed capacity planning.

Georgiadis and Athanasiou (2013) proposed improved capacity planning that produces greater economies of scale compared to Georgiadis et al. (2006) and Vlachos et al. (2007). They include both expansion and contraction activity because they consider the full product lifecycle, unlike Vlachos et al. (2007). Also, again unlike Vlachos et al. (2007), Georgiadis and Athanasiou (2013) do not consider the review period as the decision variables. In addition, since they have large initial capacity expansion, a large initial investment is needed. However, they produce very powerful uncertainty adaptability because their decision-making focuses only on proportionality.

Sudarto et al. (2014) adopt efficient capacity planning from Vlachos et al. (2007). But they include a limited budget for capacity planning. The limited budget exists because they use an RLSR model instead of an ordinary RL model like Georgiadis et al. (2006), Vlachos et al. (2007), and Georgiadis and Athanasiou (2013). The limitation of the budget refers to the social responsibility fund that is generated from the premium price. Here, the social contribution level policy to generate such a fund is assigned to work together with the capacity planning policy. These features deliver a small initial investment for RL but reduces the adaptability to lifecycle uncertainty. In addition, since they only consider a limited product lifecycle, they only have expansion activity in their capacity planning.

The proposed efficient flexible capacity planning combines features of Sudarto et al. (2014) for the efficiency term in RLSR and Georgiadis and Athanasiou (2013) for the flexibility. Therefore, it requires a small initial investment with a smaller sacrifice in terms of loss of adaptability to lifecycle uncertainty. By covering the full product lifecycle, it includes both expansion and contraction activity. In addition, the proposed decision variables that combine both proportionality and the review period will lead to higher economies of scale for capacity planning compared to those two research groups. So the proposed capacity planning deals with the difficult trade-off between efficiency and flexibility to counter the ripple effect in the supply chain (Ivanov, Sokolov, & Dolgui, 2014) because of product lifecycle disruption. This trade-off is very important to be considered since the high vulnerability of today's supply chains to disruptions challenges not only researchers but also for managers (Wagner & Neshat, 2012).

In short, the efficient flexible capacity planning developed here has a close similarity to the capacity planning of Georgiadis (2013). Both my work and that of Georgiadis (2013) adopt a periodic review for the capacity planning mechanism that considers capacity expansion and contraction policies. However, there are three major fundamental differences between the concept of capacity planning that is developed here and that developed by Georgiadis (2013). First, the capacity planning of Georgiadis (2013) is focused on a balanced trade-off between profit and capacity utilization. In contrast, this thesis focuses on a balanced trade-off between sustainability dimensions' performance and the existence of a social responsibility fund to support the entire reverse channel. This difference means that here the capacity planning has to solve a much more complex task. Second, the structure of the capacity planning model of Georgiadis (2013) adopts a self-discarding rate of capacity due to its average capacity lifetime. In contrast, such a structure is not adopted here. Here, the capacity planning has a balance loop for capacity contraction that is driven by the desired capacity discrepancy. This second difference leads us to the last key difference, which is the product lifecycle. The model of Georgiadis (2013) did not consider the nature of the product lifecycle pattern disruption in the capacity planning. In contrast, here the capacity planning considers this disruption. So, put simply, these key differences highlight the ways in which the capacity planning described in this chapter differs from the work of Georgiadis (2013), even if they seem to be very similar.

4.3 Efficient flexible long-term capacity planning

This section is divided into two parts. First, the efficient flexible long-term capacity planning is discussed. Here the SD model of the proposed capacity planning including its mathematical model and solver algorithm are described. Second, the SD model of the supply chain with RLSR to which the proposed capacity planning is attached is discussed. Therefore the synergy between the proposed capacity planning feature and the needs of such a feature in a supply chain with RLSR can be shown.

Table 4.2 Comparison of features in research on capacity planning for reverse logistics and reverse logistics social responsibility

Features	Georgiadis et al. 2006	Vlachos et al. 2007	Georgiadis 2013	Georgiadis & Athanasiou 2013	Chapter 3	Proposed capacity planning
Name	Early stage	Efficient	Efficient flexible	Flexible	Efficient	Efficient flexible
Economies of scale	√	√	√	√	√	√
Product lifecycle	Full	Limited	Limited	Full	Limited	Full
Decision options	Expansion and contraction	Expansion	Expansion	Expansion and contraction	Expansion	Expansion and contraction
Decision variables	Proportionality	Proportionality and review period	Proportionality and review period	Proportionality	Proportionality and review period	Proportionality and review period
Adaptability to uncertainties	++	+	++	+++	+	++
Initial investment	+++	+	+	+++	+	+
Investment trade-off	None	None	None	None	Limited budget	Limited budget

Legend:

\+ It has less powerful adaptability to uncertainties/it needs a small initial investment

++ It has powerful adaptability to uncertainties

+++ It has very powerful adaptability to uncertainties/it needs a large initial investment

4.3.1 System dynamics model of efficient flexible long-term capacity planning

Here, most of the cost parameters are typical in supply chain management. The assumptions are that all of the cost parameters associated with the forward supply chain are constant over time and the related costs are proportional to the product flows. But, since the cost modeling in the reverse supply chain is more complicated due to the capacity construction costs, which generally depend on the magnitude of the capacity expansion and are subject to economies of scale, this chapter adopts the general cost structure for capacity acquisition proposed by Nahmias (2001), which represents a wide variety of industries.

In detail, the social responsibility contribution levels refer to Chapter 3. The detail of the control-theory-based capacity planning mechanism used in this model is illustrated in **Fig. 4.2. Figure 4.2** shows a causal loop diagram of the recycling capacity control mechanism for efficient flexible capacity planning.

The model has a synergetic feature of efficiency taken from Sudarto et al. (2014) and flexibility taken from Georgiadis and Athanasiou (2013). The efficiency refers to $\boldsymbol{Pr}$, or the review period of capacity planning, which is contained in *RC_Discrepancy*. Therefore, the early stage expansion and frequent reviews that exist in the model of the second research group can be avoided. So the occurrence of unused capacity that is generated from early stage expansion is avoided. On the other hand, $\boldsymbol{K_{r_1} and\ K_{r_2}}$, or proportionality of expansion and contraction, are adopted from the second research group, whereas the first research group only has an expansion policy. These two decision variables belong to *RC_Expansion_Rate* and *RC_Contraction_Rate*, respectively.

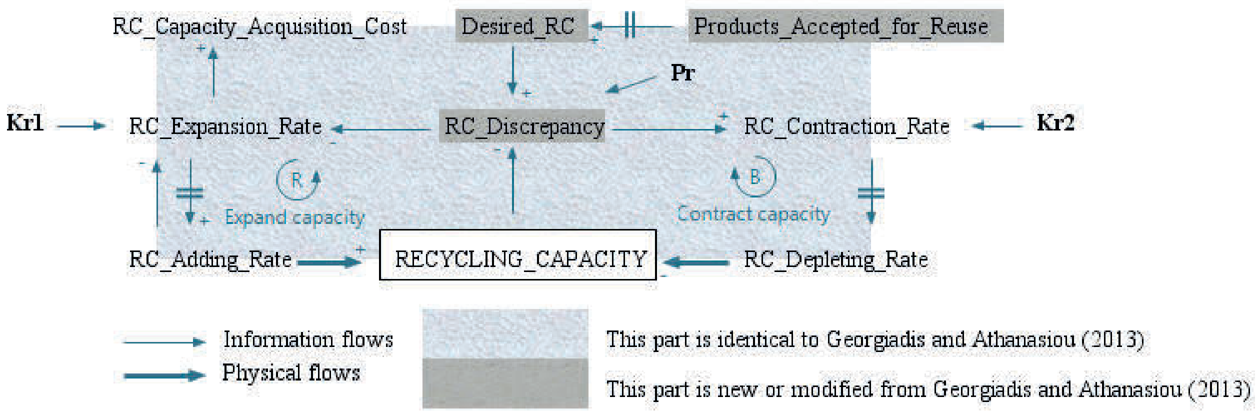

Fig. 4.2 Causal loop diagram of efficient, flexible recycling capacity planning policy

In brief, the recycling capacity expansion (*RC_Expansion_Rate*) and contraction (*RC_Contraction_Rate*) decisions depend on the discrepancy (*RC_Discrepancy*) between the desired (*Desired_RC*) and the actual level of *RECYCLING_CAPACITY*. *Desired_RC* arises by adding the desired level of capacity for the products accepted for reuse (*Products_Accepted_for_Reuse*). This mechanism is comparable to that of Georgiadis and Athanasiou (2013). However, unlike their mechanism, the one in this model is limited by the social responsibility levels (*SR_Level*) contained in *Desired_RC*. *Desired_RC* is defined as a first order exponential smoothing of *Products_Accepted_for_Reuse*. *RC_Discrepancy* reflects the system's error in actual capacity. A feedback controller determines *RC_Expansion_Rate* as capacity expansion (contraction) decisions to reduce error (expansion decisions correspond to the size y used in the capacity acquisition cost function $f(y)$). Based on a proportional control, the magnitude of each decision is defined by using the decision variables K_{r_1} (for expansion) and K_{r_2} (for contraction). On the other hand, the period of review is defined by using the decision variable Pr for both expansion and contraction. All the functions are expressed in **Eqs. (4.1)** to **(4.4)**.

$$\text{RC\_Expansion\_Rate(t)} = \begin{cases} \max(0, \text{RC\_Discrepancy(t)} \times K_{r_1}), & \text{RC\_Discrepancy(t)} > \text{lb and RC\_Adding\_Rate} = 0 \\ 0, & \text{Otherwise} \end{cases} \tag{4.1}$$

$$\text{RC\_Contraction\_Rate(t)} = \begin{cases} \max(0, -\text{RC\_Discrepancy(t)} \times K_{r_2}), & -\text{RC\_Discrepancy(t)} > 0 \\ 0, & \text{Otherwise} \end{cases} \tag{4.2}$$

$$\text{RC\_Discrepancy(t)} = \begin{cases} \text{Desired\_RC(t)} - \text{RECYCLING\_CAPACITY(t)}, & \text{t} = \text{n x Pr } \textit{where } \text{n} = 1, 2, 3, \ldots \\ 0, & \text{Otherwise} \end{cases} \tag{4.3}$$

$$\text{Desired\_RC}(t) = \begin{cases} 0, & \text{SR\_Level} > 0 \\ \text{delay}_1(\text{Products\_Accepted\_for\_Reuse}(t), \text{a\_RC}, \text{Products\_Accepted\_for\_Reuse}), & \text{Otherwise} \end{cases}$$

(4.4)

Similarly to the work of Georgiadis and Athanasiou (2013), the values of K_{i_j} characterize the recycling capacity planning policies as either trailing $(0 \leq K_{i_j} < 1)$, matching $(K_{i_j} \approx 1)$, or leading $\left(K_{i_j} > 1\right)$. In contrast, the value of Pr in our model can be either trailing $(Pr = 1)$ or leading $(Pr > 1)$ (Sudarto et al. 2014). The model continuously evaluates the emerging value of *RC_Discrepancy*. However, a new capacity expansion may be decided only when (see **Eq. (4.1)**): (A) the magnitude of discrepancy is above a threshold value *lb* (*lb* = 5% of peak demand (*Peak_Demand*)) expressing the undesirability of frequent small changes; and (B) The magnitude of expansion, based on the previous related decision, becomes fully operational, for example, *RC_Adding_Rate* = 0. (C) The fund for expansion is sufficient due to the fact that a strategy that allows new capacity expansions before previously determined capacity becomes fully operational ignores the "in progress" transition of operations.

A lead time elapses between making a decision on capacity expansion/contraction and the realization of this specific decision. *RC_Adding_Rate* in **Eq. (4.5)** and *RC_Depleting_Rate* in **Eq. (4.6)** capture this delay based on exponential smoothing of *RC_Expansion_Rate* and *RC_Contraction_Rate* respectively. **Equations (4.5)** and **(4.6)** define these variables using approximation of a third-order delay function, with average delay time T_{exp} and T_{contr} respectively, encountering an input pulse of *RC_Expansion_Rate* or *RC_Contraction_Rate*.

$$\text{RC\_Adding\_Rate}(t) = \text{delay}_3(\text{CC\_Expansion\_Rate}, \text{T}_{\text{exp}}, 0)$$

(4.5)

$$\text{RC\_Depleting\_Rate}(t) = \text{delay}_3(\text{CC\_Contraction\_Rate}, \text{T}_{\text{contr}}, 0)$$

(4.6)

Finally, the actual recycling capacity (*RECYCLING_CAPACITY*) is defined by **Eq. (4.7)** as follows:

$$\text{RECYCLING\_CAPACITY}(t) = \int_0^t (\text{RC\_Adding\_Rate}(t) - \text{RC\_Depleting\_Rate}(t)) \text{ x dt} + \text{RECYCLING\_CAPACITY}(t = 0), \text{where RECYCLING\_CAPACITY}(t = 0) = 0$$

(4.7)

A similar modeling approach is applied to the *COLLECTION_CAPACITY*. The only difference is that the desired level arises as a first order exponential smoothing of used products (Used_Products), unlike in Georgiadis and Athanasiou (2013), where it comes from the *Sales* of previous products since they are considering multiple products. Following the standard RL practice, collectors have direct access to this source of information, using Pc, K_{C_1}, and K_{C_2} as the decision variables for the review period of capacity expansion/contraction, capacity expansion, and capacity contraction respectively. Consequently, Pc, K_{C_1}, and K_{C_2} are the decision variables for the collection facility and Pr, K_{r_1}, and K_{r_2} are the decision variables for the recycling facility. So K_{i_j} and P_i describe the capacity planning policies with $i = 1$ for the collection facility and 2 for the recycling facility, and $j = 1$ for expansion and 2 for contraction.

The efficient flexible capacity planning policy is delivered by solving the mathematical model below. This mathematical model uses the mathematical model from Georgiadis and Athanasiou (2013) as the basis. So the term near optimal (*nopt*) model adopted in this chapter is similar to theirs. Then it is modified to accommodate the focus on sustainability dimensions and the need to become efficient.

$$\text{Objective function} = \begin{cases} Min\ \Delta C_{Profit} \\ Min\ \Delta C_{environmental} \\ Min\ \Delta C_{social} \end{cases} \tag{4.8}$$

Where:

$$\Delta C_{Profit}\ (Min\ Kr_1, Max\ Pr \mid System\ Dynamics\ Model) = ((NPV)^{nopt} - (NPV)^{flex})/(NPV)^{nopt} \tag{4.9}$$

$$\Delta C_{environmental}\ (Min\ Kr_1, Max\ Pr \mid System\ Dynamics\ Model) = ((SGI)^{nopt} - (SGI)^{flex})/(SGI)^{nopt} \tag{4.10}$$

$$\Delta C_{social}(Min\ Kr_1, Max\ Pr \mid System\ Dynamics\ Model) = ((SSB)^{nopt} - (SSB)^{flex})/(SSB)^{nopt} \tag{4.11}$$

Constraints:

$$\Delta C_X \leq \delta; where\ x = profit, environmental, and\ social \tag{4.12}$$

$$0 \leq Kr_1 \leq L_1^K \tag{4.13}$$

$$0 \leq (Kr_2, Kc_1, Kc_2) \leq L_2^K \tag{4.14}$$

$$0 \leq \mathrm{Pr} \leq L_1^P \tag{4.15}$$

$0 \leq Pc \leq L_2^P$ **(4.16)**

Where:

1. **Equation (4.8)** is the objective function for minimizing the sustainability dimensions performance loss.
2. **Equations (4.9)** to **(4.11)** are the detailed functions of the objective function. The aim is to minimize the aggressiveness of capacity expansion and to have a less frequent review period for capacity planning.
3. **Equation (4.12)** represents the acceptable bounded sustainability dimensions performance loss with X = 1, 2, and 3 and 1 = profit, 2 = environmental, and 3 = social.
4. **Equations (4.13)** and **(4.14)** represent the boundaries of the aggressiveness of decision variables.
5. **Equations (4.15)** and **(4.16)** represent the boundaries of the frequent review period of decision variables.
6. $(NPV)^{flex}$ is the net present value of *Total_Supply_Chain_Profit* (economic performance) using the efficient flexible capacity planning model, while $(NPV)^{nopt}$ is that achieved by the near-optimal model.
7. $(SGI)^{flex}$ is the cumulative green image achieved by the supply chain (environmental performance) using the efficient flexible capacity planning model, while $(SGI)^{nopt}$ is that achieved by the near-optimal model.
8. $(SSB)^{flex}$ is the cumulative social benefit achieved by the supply chain (social performance) using the efficient flexible capacity planning model, while $(SSB)^{nopt}$ is that achieved by the near-optimal model.

In particular, the model minimizes the value of Kr_1 and maximizes Pr under the restriction of the maximum acceptable loss of sustainability dimensions' performance or δ (%), while the actual loss of performances is measured by ΔC_{Profit} as a percentage of $(NPV)^{nopt}$, by $\Delta C_{environmental}$ as a percentage of $(SGI)^{nopt}$, and by ΔC_{social} as a percentage of $(SSB)^{nopt}$. The value of Kr_1 is limited by the value of L_1^K, defined as a continuously decreasing upper bound of Kr_1 in each iteration of the procedure. The rest of the capacity planning decision variables (Kr_2, Kc_1, Kc_2) are limited by a much more relaxed upper bound, equal to L_2^K. In addition, the value of Pr is limited by the value of L_1^P, defined as a continuously increasing upper bound of Pr in each iteration of the procedure. The rest of the capacity planning decision variables (Pc) are limited by a much more relaxed upper bound, equal to L_2^P. The search algorithm used to track the values of Ki_j^{flex} and Pi^{flex} is given below. We consider a set M {1, …, m} of m experimental runs. For a given δ, the procedure considers two subsets; subset F_δ (the set of experimental runs with feasible solutions) and subset L_δ (the set of experimental runs without feasible solutions), where $F_\delta \cup I_\delta$ and $F_\delta \cap I_\delta = \emptyset$. The procedures from **Step 1** to **Step 14** used here are comparable to the solver algorithm used in Georgiadis and Athanasiou (2013).

- **Step 1**: Initialization: 1.1. Set the values of $L_1^K \; and \; {L_2^K}_1$, the lower and upper bounds of δ^{profit} (δ_{Low}, δ_{Up}) and the step-increase of δ ($\Delta\delta$). 1.2. Set $\delta = \delta_{Low}$, and go to **Step 2**.
- **Step 2**: Set counter $c_{\delta profit} = 0$, $I_{\delta profit} = \emptyset$, $F_{\delta profit} = \emptyset$, M = {1 … m} and go to **Step 3**.

- **Step 3**: Set $C_\delta = C_\delta + 1$ and go to **Step 4**.
- **Step 4**: Solve the nopt-model, obtain Ki_j^{nopt} and$(NPV)^{nopt}$, and go to **Step 5**.
- **Step 5**: Solve the efficient flexible-model (*flex*). If the model has a feasible solution then set $F_\delta = F_\delta \cup C_\delta$, obtain Ki_j^{flex} and $(NPV)^{nopt}$, and go to **Step 6**, else set $I_\delta = I_\delta \cup C_\delta$ and go to **Step 8**.
- **Step 6**: If $Kr_1^{flex} = L_1^K$ then go to **Step 7**, else set $L_1^K = Kr_1^{flex}$ and go to **Step 5**.
- **Step 7**: Solve the nopt-model under the restriction that $Kr_1 = Kr_1^{flex}$ and obtain the values of Kr_2 ,Kc_1, Kc_2, and NPV. Set $Kr_2^{flex} = Kr_2, Kc_1^{flex} = Kc_1, Kc_2^{flex} = Kc_2$, and $(NPV)^{flex} = NPV$ and go to **Step 8** (in this case, the nopt-model returns an NPV value equal to or greater than that obtained in **Step 5**).
- **Step 8**: If $C_\delta = m$ then go to **Step 9**, else go to **Step 3**.
- **Step 9**: If $\delta = \delta_{Up}$ then go to **Step 10**, else set $\delta = \delta + \Delta\delta$ and go to **Step 2**.
- **Step 10**: The end of solving steps for minimum Kr_1 to ΔC_{Profit}. Return subset F_δ and the values of Ki_j^{flex} and $(NPV)^{flex}$ $\forall$ $C_\delta \in F_\delta$ and $\forall$ δ, and return subset I_δ.
- **Step 11**: Restart at Step 1 but change the focus from Kr_1 to Pr.
- **Step 12**: Restart at Step 1 but change the focus from the profit (economic) dimension to the environmental dimension.
- **Step 13**: Restart at Step 1 but change the focus from the environmental dimension to the social dimension.
- **Step 14**: End. The solutions are created.

4.3.2 System dynamics model of supply chain with reverse logistics social responsibility

A Causal Loop Diagram (CLD) is a part of the SD model validation (Bhattacharjee & Cruz, 2015; Sterman, 2002) and builds confidence in the model (Barlas, 1996; Forrester & Senge, 1979). In contrast, a Simplified Causal Loop Diagram (SCLD) shows only the most important loops in the model. The most common characteristic form of the enhanced box is ended by the word "RULE"; for example "Production and Distribution RULE". SCLD is commonly used in a complex SD model, such as the SD model of Georgiadis and Besiou (2008).

Fig. 4.3 shows the SCLD in this study and the simulation is built by using Anylogic software. It consists of four main loops: two Balance loops (B1 and B2) and two Reinforcement loops (R1 and R2), similarly to the work in Chapter 3. The explanation for these four main loops is presented below.

- R1 reveals that the SD model is considering a pull system, where *Demand* drives *Production*;
- B1 represents how *Demand* will decrease as the social responsibility contribution levels (*SR_Level*) increase: there is a *Price* hike to the *Premium_Price*, which causes a *Demand* loss;
- R2 represents the reinforcement of *Demand* by the model after the RLSR activity that is financed by the *SR_Fund*, which then produces environmental performance;
- Last, B2 represents incompliance with *Legislation*, which will damage the supply chain economic performance (*Total_Supply_Chain_Profit*) (Georgiadis & Besiou, 2008).

Specifically, the process B1 will produce a social responsibility fund (*SR_Fund*) that will be used for financing RLSR. This loop adapts the mathematical model of a *Price* hike that limits *Demand* (Hsueh & Chang, 2008) but is improved by adding *Demand* recovery and *Demand* improvement features.

Fig. 4.3 highlights the need of policy makers to carefully consider their policies, since there is a trade-off between *Demand* loss and *Demand* recovery in the *Demand* improvement process with the need to comply with the *Legislation* (*Legislation_Compliance*) standard and the existence of a *Penalty*. However, unlike in Chapter 3, here the product lifecycle with its inherited uncertainty is considered. Accordingly, the capacity planning changes to become efficient and flexible in the long-term in order to tackle this issue using expansion and contraction options to better advance the economies of scale and economic performance. Also, there are some modifications in the sustainability dimensions' performance measurement to accommodate the need for the capacity planning to become efficient and flexible.

In addition, **Fig. 4.4** gives a clearer description of the CLD in the system under study. It shows more SD model entities that correspond to real world entities, unlike **Fig. 4.3**. While **Fig. 4.3** is built to show the most important loops in the system simply, **Fig. 4.4** is built to show the system complexity itself, including the relationship between CLD and the most closely related papers. As shown in **Fig. 4.4**, the base of the SD model supply chain is mainly built upon the two most closely related papers – including the data of the model – namely (Vlachos et al., 2007) and (Georgiadis & Besiou, 2008). The social responsibility RULE is developed based on (Sudarto et al., 2014). In addition, the capacity planning is proposed in this chapter, but the data for the product lifecycle with its inherited uncertainties are taken from (Georgiadis, Vlachos, & Tagaras, 2006). So in short, here the model adopts secondary data.

The works of Georgiadis and Besiou (2008) and Vlachos et al. (2007) are the basis of the RLSR SD model of Sudarto et al. (2014) that is used as the major reference in this chapter. Georgiadis and Besiou's model (2008) proposes how ecological motivations influence the RL economic performance. Their model is adopted in B2 and R1 since their model represents how RL capability complies with *Legislation* through ecological motivation to avoid a *Penalty*. But, because the collection capacity (*COLLECTION_CAPACTY*) and the recycling capacity (*RECYCLING_CAPACITY*) in their model are assumed to be static, the environmental dimension (Green Image = GI) will always be constant. Also, no social performance (*Social_Performance*) is measured. So, no social to economic return can be gained. Such limitations are overcome in our model by adding additional features, namely dynamic long-term efficient flexible capacity planning and social performance measurement. On the other hand, Vlachos et al. (2007) proposed a theoretical mechanism of efficient capacity planning in the SD approach. Their model is adopted in our R1, since the actors involved are the same as the social-responsibility-impacted actors in the supply chain and the actors performing the same activity, that is, RL. But since Vlachos model does not consider the source of funding for financing RL, limitless capacity planning could be adopted in their SD model. In addition, no social performance is measured, so the social to economic return cannot be examined. Therefore, this limitation is overcome by limiting the capacity planning policy with the existence of the *SR_Fund*. In addition, since they do not consider the full product lifecycle, they only have an expansion option in their capacity planning. In contrast, our capacity planning has expansion and contraction options since we are dealing with the full product lifecycle.

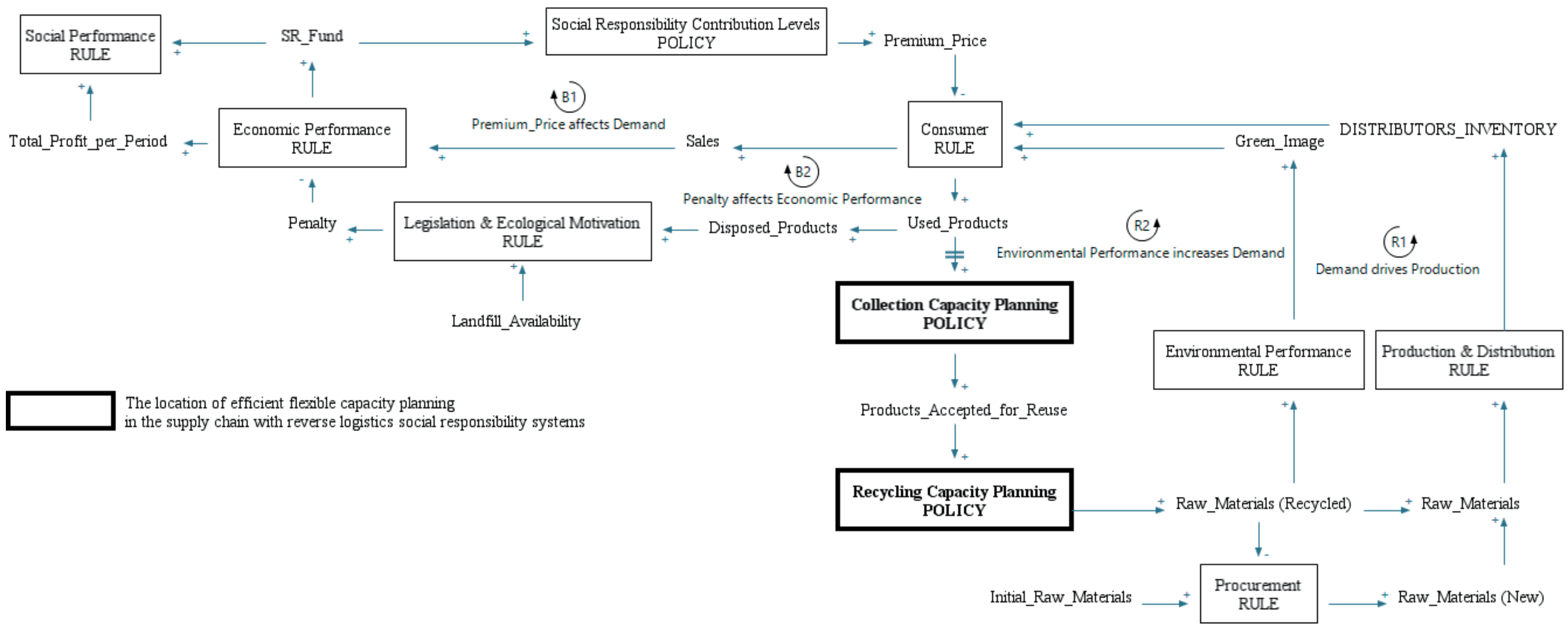

Fig. 4.3 Simplified causal loop diagram of supply chain with reverse logistics social responsibility

Then, as mentioned in **Section 4.1**, the policy options in the model consist of [1] the social responsibility policy (*SR_Level*) and [2] the capacity planning policy (*COLLECTION_CAPACITY* and *RECYCLING_CAPACITY*). In this chapter, the policy parameters are simplified, as already explained in **Section 4.3.1**. According to **Fig. 4.3**, the first policy refers to the Social Responsibility Contribution Levels POLICY and the other policies refer to the Collection Capacity Planning POLICY and the Recycling Capacity Planning POLICY.

The first policy is represented by the *SR_Level* constant in the SD model with a dimensionless unit (Hsueh & Chang, 2008). *SR_Level* refers to how much the *Price* will be increased to give the *Premium_Price*. The range of policy values is set between 0 and 1, where 0 means that no social responsibility is performed in the supply chain, so there is no *Price* hike, while 1 means that social responsibility is performed in the supply chain with 100% *Price* hike or the *Price* is doubled. In the end, this policy will adjust the *Demand* loss but the supply chain will start to provide *SR_Fund* to finance RLSR activity. The assumption in the Consumer RULE is that the *Demand* loss will be adjusted based on the consumer segmentation. The segments range from high social responsibility sensitivity (willingness to buy more expensive products in exchange for social responsibility value) to low social responsibility sensitivity. Each segment has its own range of threshold values for the *Price* hike to maintain its *Demand* for the product.

The first policy is used to adjust the *Price* to earn the *SR_Fund* in order to achieve optimal economic and social performance results, whereas the other policy is used to adjust the RLSR capacity planning for optimal usage of the *SR_Fund* to achieve the optimal environmental performance. The collection capacity planning policy is represented by $Pc, K_{C_1},$ and K_{C_2} in the SD model with the week as the unit of Pc and K_{C_1} and K_{C_2} having dimensionless units. Pc represents the length of the review period for *COLLECTION_CAPACITY* expansion (Chapter 3) and contraction, where the range of the policy can be from 1 to *n*, where 1 refers to frequent reviews (adopted in non-efficient capacity planning, e.g. Georgiadis and Athanasiou 2013), and *n* refers to less frequent reviews. A larger value of *n*, will produce greater savings from economies of scale but will decrease the flexibility of capacity planning. The economies of scale are the core of our cost structure assumption in the capacity planning, where a larger increment of capacity produces a lower cost of unit-based capacity expansion (Georgiadis & Athanasiou, 2010; Georgiadis et al., 2006). Then, K_{C_1} and K_{C_2} represent control variables of proportionality of expansion and contraction for COLLECTION_CAPACITY (Georgiadis & Athanasiou, 2013), where the range of the policy can be from 1.0 to 3.0, where 1.0 refers to less aggressive capacity expansion and 3.0 refers to aggressive capacity expansion. In the end, this policy will adjust the actual value of *COLLECTION_CAPACITY*. The recycling capacity planning policy has the same structure as the second policy, but it is assigned to *RECYCLING_CAPACITY* building and is represented by $Pr, K_{r_1},$ and K_{r_2}. So, in brief, one policy is adopted from Sudarto et al. (2014) to achieve efficiency and the other is taken from Georgiadis and Athanasiou (2013) to achieve flexibility in capacity planning policy. Then, the capacity planning is revised to align with the first policy to make sure the capacity planning will receive enough support from the social responsibility fund.

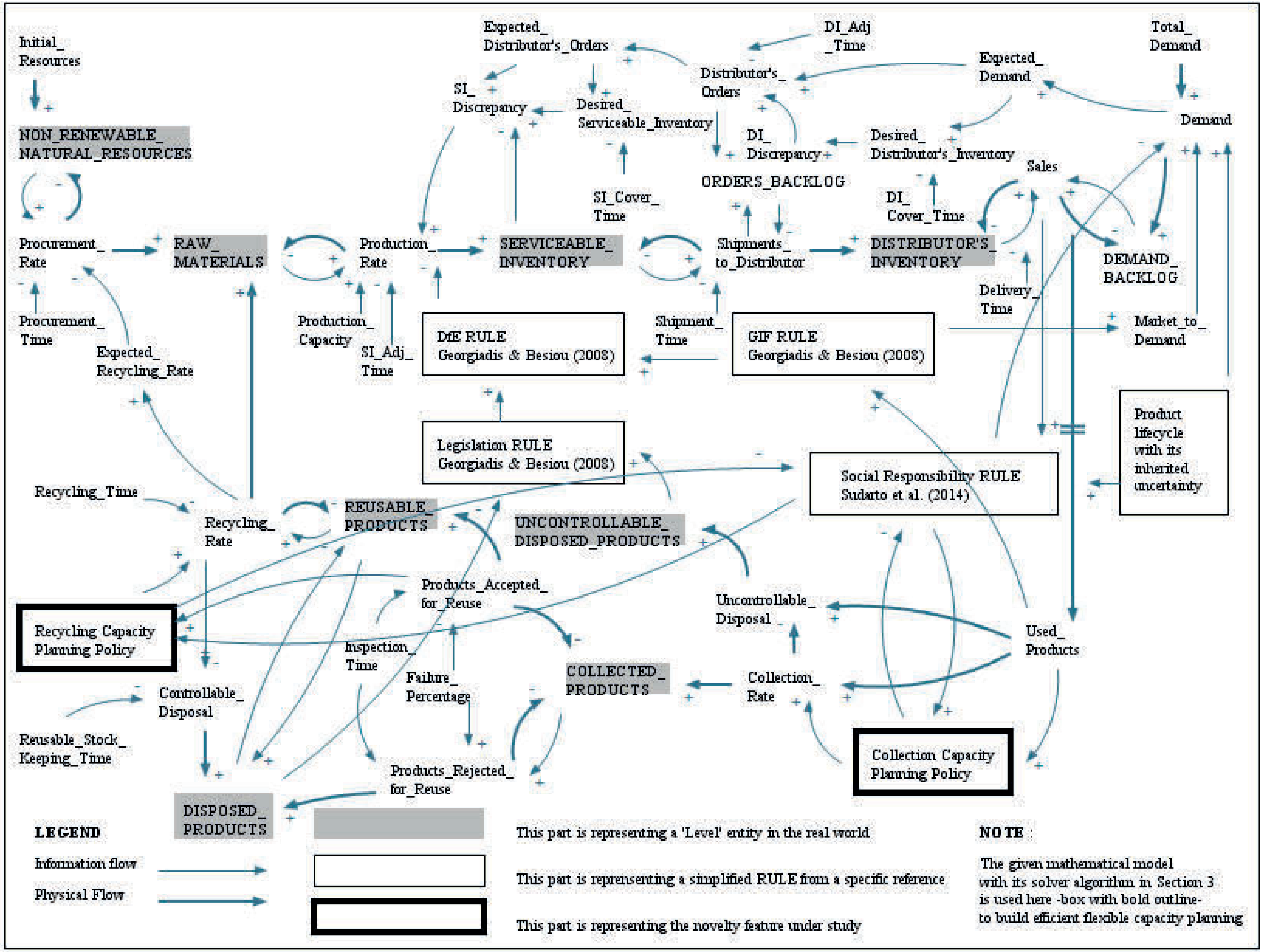

Fig. 4.4 Causal loop diagram of supply chain with reverse logistics social responsibility

In addition, there are another two key features used in the system under study related to **Fig. 4.3.** The first feature represents how each market segment reacts to the premium price. This function belongs to *MR_Results* in the Social Responsibility RULE in **Fig. 4.3.** The second feature represents how much the demand is shifting due to the increase in environmental performance. So, put simply, the first feature represents the demand elasticity in the system and the second represents the scale of the impact because of the relationship between sustainability dimensions. So both features have a great impact on the system settings in this study, since one of them is the key to the social responsibility elements for generating the social responsibility fund and the other is the key to the interrelated sustainability dimensions in this study. So the formulation of both the novel social responsibility elements and the interrelated sustainability dimensions now becomes clearer.

Lastly, the simulation of the SD model is run and the performance dimensions are used to consider the policy effectiveness with the relationship between performance dimensions as shown in **Fig. 4.3.** The performance dimensions are measured in the following sequence: first, the economic performance; second, the social performance based on economic return from RLSR activity; and finally, the environmental performance as the result of RL activity. Detailed information on the measured performance dimensions is given below:

a. Economic dimension performance

   This is represented by the *Total_Supply_Chain_Profit* variable, which is defined as the net present value (NPV) of the total supply chain profit, with the euro as the unit. The equation is expressed as shown in **Eq. (4.17).**

b. Environmental dimension performance

   This is represented by the *GI* variable, which is defined as the cumulative change in green image produced by the RLSR activity and has a dimensionless unit. The equation is expressed as shown in **Eq. (4.18).** It is derived from the collective result of the change in green image per period. The range of values is between 0 and $+\infty$.

c. Social dimension performance

   This is represented by the *Social_Performance* variable, which is defined as the cumulative social performance based on social responsibility activity by considering the economic return and optimal usage of the SR_Fund. The unit is (euros/week)/week and the function is expressed in **Eq. (4.19).** Now, the relationship between social responsibility and economic performance is clearly shown. Also, the ratio of *SR_Fund* to spending of the SR_Fund is measured because the virtual benefits of the social responsibility can be assumed to be equivalent to the amount of money spent on social responsibility activity. The range of values is between $-\infty$ and $+\infty$. The minus sign means that the activity produces economic loss and the plus sign means that it produces a profit.

$$\text{Total\_Supply\_Chain\_Profit} = \text{NPV}(\text{Total\_Profit\_per\_Period}, \text{Discount\_Factor}, 0, 1, 0.01) \quad (4.17)$$

$$\text{GI}(t) = \int_0^t (\text{Periodic\_GI}) \times dt \quad (4.18)$$

$$\text{Social\_Performance}(t) = \int_0^t (\text{SR\_Fund} == 0?\ 0: \text{Total\_Profit\_per\_Period} * (\text{SR\_Spending\_Rate}/\text{SR\_Fund})) \times dt \quad (4.19)$$

4.4 Experimental Design

The experimental design is divided into two parts. The first is the SD model validation and the second is the running of the numerical experiment for the efficient flexible capacity planning. So it is ensured that the numerical experiment is run on a valid SD model.

4.4.1 System dynamics model validation

The first procedure aims to validate the model. In this step, before the model is validated, the basic scenario is defined with array settings, as shown in **Appendix A,** with 300 weeks as the simulation period. The simulation is designed with the week as the unit of the period and the euro as the unit of currency. The data used are taken from previous related simulation researches as discussed in **Sections 4.2** and **4.3** (Georgiadis & Athanasiou, 2013; Georgiadis et al., 2006). Here, Anylogic is used as the simulation software.

The results of the proposed SD model validation are described in three steps (Forrester & Senge, 1979; Sterman, 2002). First, in the Anylogic software test, no dimensional inconsistency or error was found. Second, it was possible to continue to the next step, namely the extreme-condition test. In this step, all level-type entities' initial inventories are set as 0 with no legislation (*Legislation*) and no raw materials (*Initial_Non_Renewable_Materials* is set as 0). Then after the simulation, the results show that there is no procurement (*Procurement* = 0), no production (*Production* = 0), no shipment from the manufacturer to the distributor (*Shipment* = 0), no delivery to the customer (*Delivery* = 0), or no sales (*Sales* = 0) with no reverse logistics activity (*COLLECTION_CAPACITY* = *RECYCLING_CAPACITY* = 0). Then, the measured performance dimensions produce zero-value performances (*Total_Supply_Chain_Profit* = *GI* = *Social_Performance* = 0). The last test is a behavior-pattern test; in this case the *SR_Level* is set to 0.2 and then the simulation is run. The behavior of two variables is checked against the behavior shown by previous research. The results of the simulation are that the collection percentage (*Collection_Percentage*) and the recycling percentage (*Recycling_Percentage*) are in agreement with the results of Georgiadis and Besiou (2008).

4.4.2 Numerical experiment

The algorithm and mathematical model described in **Section 4.3** will be used to run the experiment, which employs Taguchi Experiment Design. **Table 4.3** shows the control factors (inner array) with their sets of levels. The control factors are two key policy parameters for achieving efficient and flexible capacity planning, named *SR_Level* for the level of social responsibility contribution and $\boldsymbol{\delta}$ for the level of acceptable loss of sustainability dimensions performance**. Table 4.4** is called a noise-factor or outer-array table. It shows the product lifecycle with its sets of levels.

The value of each level in **Table 4.3** is generated by the following steps. First, the *SR_Level* is set based on the value given in Chapter 3, with the lowest value as the initial value of the lower bound or (–) value. Second, the values of the rest of the policy parameters are set. The lowest values given in Vlachos et al. (2007) and Georgiadis and Athanasiou (2013) are set as the initial values for their (–) values. Third, the values are tested in the preliminary simulation. Lastly, on a sequential basis, the values are changed (expanded) heuristically to find the range of solutions for the combination of set values of policy parameters given in **Table 4.3**. The heuristic methods reference value of δ for the initial value is taken from Georgiadis and Athanasiou (2013). Once a parameter has been changed, the others are set to remain constant. The values are set within the range of policy parameter settings that can meet the two most critical conditions: first, the *SR_Fund* should always be available to finance RL activities, and second, due to the complexity of our performance dimensions, the values given in **Table 4.3** should have enough capability to show a wide impact on all dimensions of performance. So, in the end, they can be representative of a broad range of policy parameter settings that could show a wide impact on performances in RLSR. Therefore, these specific values can meet the research needs of this study.

On the other hand, the value of each level in **Table 4.4** is equal to that given by its parameter settings and Georgiadis et al. (2006). **Table 4.4** can be representative of a broad range of both product lifecycle types and recyclable products, and therefore all these typical values for the recycling industry in **Table 4.4** are still adopted, since these values represent the characteristics of the recycling industry in general. This means that these values can represent the recycling industry with social responsibility aspects, which are considered in the study in this chapter.

In addition, remanufacturing is a specific type of recycling (Bernard, 2011). The research reported in this chapter focuses on social responsibility issues in CLSCs with either a recycling network or a remanufacturing (a specific type of recycling) network, as in Nikolaou et al. (2013). Therefore, some of the product families mentioned in Georgiadis et al. (2006) could be representative for the needs of this chapter. In addition, a real-world example of the proposed model, as stated in **Section 4.1,** belongs to the stated product families in my work.

In view of that, following the approach and adopting the terminology of Taguchi's parameter design, the numerical experiment is set up as a product array experiment, where two separate experimental designs (arrays) are used and observations are recorded for all combinations of the two designs. The outer array (noise factors) is a full factorial design with $2 \times 3^2 = 18$ combinations, whereas the inner array (control factors) is a 2^2 full fractional factorial design. The total number of experimental runs is $18 \times 4 = 72.$ For each of the 18 combinations of the noise array, the four combinations of control array provide *n* heuristics observations of the policy parameters. Therefore, the efficient flexible algorithm can be used to determine the values of other policy parameters such as $K_{C_1},\ K_{C_2},\ K_{r_1},\ K_{r_2},\ Pc,$ and Pr, which should be set to minimize the sustainability dimensions' performance loss.

Table 4.3 Policy parameters with their sets of levels (control factors/inner array)

Noise factors	(−)	(+)
SR_Level	0.2	0.3
$\boldsymbol{\delta}$	10%	20%

Table 4.4 Product lifecycle with it sets of levels (noise factors/outer array)

Control factors	Sets of level		
Lifecycle (weeks)	250 (medium)		500 (long)
Pattern (length of the maturity stage)	Pattern 1[a]	Pattern 2[b]	Pattern 3[c]
Residence Index (RI) [d]	0.2 (Low)	0.35 (Medium)	0.5 (High)

[a] Length of maturity stage equal to 3/5 of lifecycle

[b] Length of maturity stage equal to 1/3 of lifecycle

[c] Length of maturity stage equal to 1/5 of lifecycle

[d] Residence Index $= \frac{\mu_{Resident\ Time}}{Lifecycle}$

All 72 combinations of experimental runs have been studied over the time horizon of the lifecycle. All arrays in the system dynamics model for supporting this experimental design are set equal to the value given in **Appendix A**. The results are shown in **Tables 4.5** and **4.6** in **Section 4.5**, where Case $I_{i,j}$ and $i = 1$ to 18 refers to outer array combinations and *j* represents the social responsibility contribution levels (*SR_Level*), such as $1 = (-)$ and $2 = (+)$. The acceptable performance loss that is set by the policy maker (δ) ranges from 10 to 20%.

In brief, the discussion of the results in **Section 4.5** will focus on a comparison between the findings of this paper and those of comparable research groups such as Georgiadis (2013), Georgiadis and Athanasiou (2013), and in Chapter 3, who consider efficient flexible capacity planning, flexible capacity planning, and efficient capacity planning, respectively.

4.5 Results and discussion

The results of the numerical experiment are shown in **Tables 4.5** and **4.6. Table 4.5** shows efficient flexible control for capacity planning decision variables at $\delta = 10\%$. **Table 4.6** shows efficient flexible control for capacity planning decision variables at $\delta = 20\%$. The decision variables in both tables consist of $K_{C_1}^{flex}, K_{C_2}^{flex}, K_{r_1}^{flex}, K_{r_2}^{flex}, P_c^{flex}, and\ P_r^{flex}$.

The results in **Table 4.5** and **4.6** reveal nine findings. First, $K_{C_1}^{flex}$ has a much lower value than the value proposed by the near-optimal solution for $\delta = 10\%$ and $\delta = 20\%$. Second, $K_{C_2}^{flex}$ has a lower value than the one proposed by the near-optimal solution in both tables, except for *SR_Level* $= 0.2$ under the third and sixth conditions of uncertainty. Third, P_c^{flex} in both tables has a higher value than the one proposed by the near-optimal solution for *SR_Level* $= 0.2$, while it becomes more dynamic in the high value for *SR_Level* $= 0.3$. Fourth, $K_{r_1}^{flex}$ in both tables has a much lower value than the one proposed by the near-optimal solution for *SR_Level* $= 0.3$, while it becomes more dynamic in the high value for *SR_Level* $= 0.2$. Fifth, $K_{r_2}^{flex}$ has similar results to $K_{C_1}^{flex}$, but the value is only a little higher rather than much higher. Sixth, P_r^{flex} has similar trend to P_c^{flex}. Seventh, the range of mean percentage for economic performance in both tables is narrower for *SR_Level* $= 0.3$ than for *SR_Level* $= 0.2$. In **Table 4.5**, the mean ranges from 0.06 to 8.84% for *SR_Level* $= 0.2$ and from 0.03 to 4.12% for *SR_Level* $= 0.3$. In **Table 4.6**, the mean ranges from 1.10 to 14.68% for *SR_Level* $= 0.2$ and from 1.00 to 12.87% for *SR_Level* $= 0.3$. Eighth, the range of mean percentage for environmental performance in both tables is narrower for *SR_Level* $= 0.3$ than for *SR_Level* $= 0.2$, as for the seventh finding. In **Table 4.5**, the mean ranges from 1.47 to 9.99% for *SR_Level* $= 0.2$ and from 1.12 to 8.40% for *SR_Level* $= 0.3$. In **Table 4.6**, the mean ranges from 1.27 to 10.40% for *SR_Level* $= 0.2$ and from 1.19 to 8.30% for *SR_Level* $= 0.3$. Ninth, the range of mean percentage for social performance in both tables is narrower for *SR_Level* $= 0.3$ than for *SR_Level* $= 0.2$, as in the seventh and eighth findings. In **Table 4.5**, the mean ranges from 1.01 to 1.69% for *SR_Level* $= 0.2$ and from 1.23 to 1.91% for *SR_Level* $= 0.3$. In **Table 4.6**, the mean ranges from 1.99 to 2.67% for *SR_Level* $= 0.2$ and from 1.84 to 2.63% for *SR_Level* $= 0.3$.

Based on these nine findings, three very interesting findings emerge regarding the achievement of efficient flexible capacity planning within the range of acceptable loss of sustainability dimensions' performance (δ). First, the aggressiveness of capacity expansion of both the collection facility and the recycling facility should be designed to be moderately minimized, while the aggressiveness of capacity contraction should also be minimized. This interesting finding refers to the first, second, fourth, and fifth findings mentioned above regarding the capacity expansion and contraction decision variables in both the collection facility and the recycling facility. Second, a less frequent review period is needed for both collection and recycling facilities, while under some conditions at *SR_Level* $= 0.3$, a higher less frequent review period should be required.

This interesting finding relates to the third and sixth findings as discussed above regarding the review period decision variables. Third, the sustainability dimensions' performance could emerge simultaneously, based on the other findings compared to the first and second interesting findings – interrelated sustainability dimensions performance. However, both δ and *SR_Level* greatly affect the width of the range of the mean percentage of all performances. This means that the capacity planning with higher levels of δ and *SR_Level* leads to highly volatile performances. The performances may not only improve but could also decrease by a large percentage compared to the near-optimal solution.

These interesting findings can be explained by three factors related to the measured performances. First, the economic performance has the readable pattern of performance since it is directly influenced by the decision variables. In addition, longer delay occurs for both *Demand* and *Used_Products* because of the product lifecycle with its inherited uncertainty (P, L, and RI). Therefore, this longer delay leads to more slack time between *Sales* of new products and those products becoming *Used_Products* and, more rarely, capacity expansion. So, *Demand* and *Used_Products* become more prevalent during the time period of the simulation. Second, the environmental performance depends on the intersection between two interests. First, it is necessary to respond to *Used_Products* as soon as possible by expanding both the collection and the recycling capacity. However, this necessity is strongly limited by the time of expansion (review period), economies of scale for the expansion, and the availability of the social responsibility fund. Second, the first steps towards capacity expansion are taken after *Sales* becomes *Used_Products*. Therefore, the environmental performance goes through two slack periods before the green image can start to improve: the time between backlog demand (*Demand_Backlog*) and *Sales* and the time between *Sales* of products and *Used_Products*. In the end, both slacks cause the policy parameters to have less effect on countering the uncertainty. Lastly, social performance is the performance that is most difficult to change. This is because it reveals the need for synergy between economic and environmental performance. This condition has a high cost. If there is a disturbance or if more slack time occurs for any reason in the economic and environmental performances, there will be a direct effect on the social performance. This situation means that the social performance is the type of performance that is most difficult to influence with the policy parameters. Moreover, it also becomes the type of performance that is most vulnerable to the effects of uncertainty.

So, put simply, according to the behaviors of the performance dimensions, sound insights from the efficient flexible settings parameter are obtained mostly by reducing the aggressiveness of collection and recycling expansion. Moreover, under the condition in which the *Sales* loss becomes higher due to a larger price hike ($SR\_Level = 0.3$), the review period should be set at a higher value to obtain greater economies of scale for expansion. However, to avoid unused capacity, which will incur unnecessary cost, the contractions of both collection and recycling facilities are set lower. Therefore, these combinations of parameters settings will cause the volatility of the performances to remain within the acceptable range.

As discussed above, therefore the findings in this chapter are comparable to the findings of other research groups such as in Chapter 3, Georgiadis and Athanasiou (2013), and Georgiadis (2013), by focusing on the economic performance, the aggressiveness of capacity expansion, and the frequency of the review period. First, the aggressiveness of the proposed model is greater than in Chapter 3, since they do not adopt product lifecycle uncertainty, which need some buffer capacity. In addition the review period is less frequent, compared in Chapter 3, to compensate for the economies of scale of higher aggressiveness. Second, the aggressiveness of the proposed model is very similar to that of Georgiadis and Athanasiou (2013), since both researches adopt product lifecycle uncertainty. However, the proposed model adopts a much less frequent review period compared to that of Georgiadis and Athanasiou (2013) due to the *SR_Fund* efficiency. Third, the aggressiveness of the proposed model is lower than that of Georgiadis (2013). Even though his model does not consider any disruption, it adopts a self-discarding rate of capacity due to its average capacity time. So his model needs some more buffer capacity related to such self-discarding. However, the review period of the proposed model is very similar to that of his model, since the latter considers the balance between profit and capacity utilization, which requires high economies of scale in capacity expansion.

4.6 Summary

This chapter contributes to the relatively limited but important academic knowledge on the methods of efficient flexible capacity planning policy development for research on social responsibility issues in CLSCs in order to achieve optimal sustainability dimensions performance in the interrelated triple bottom line framework. This contribution is delivered under fixed cost and time parameter settings. It is found that the optimal sustainability dimensions performance can be delivered by the efficient flexible capacity planning while tackling the uncertainties. However, the proposed capacity planning has some limitations. This capacity planning can produce a smaller loss of sustainability dimensions performance while making a smaller sacrifice in terms of adaptability to counter the effect of the product lifecycle with its inherited uncertainty. However, policy makers need to decide on their preferred order of priority of the sustainability dimensions.

The present chapter is also relevant for managers or policy makers. While the uncertainties considered here cannot be regarded as exhaustive, they offer insights to social-responsibility-related managers to help them tackle some uncertainties in their supply chains with RLSR to achieve better performances. Moreover, the chapter offers strategic policy makers in firms additional evidence that integrating social responsibility in the supply chain can lead to the achievement of sustainability. Finally, a possible extension of the research could be the study of the other uncertainties, such as the level of used products.

Table 4.5 Efficient flexible control for capacity planning decision variables at $\delta = 10\%$

Case	Kc_1^{flex}	Kc_2^{flex}	Pc^{flex}	Kr_1^{flex}	Kr_2^{flex}	Pr^{flex}	$\overline{\Delta C}_{Profit}$	$\overline{\Delta C}_{environmental}$	$\overline{\Delta C}_{social}$
$I_{1,1}$	–	-	+	–	-	+	≈ 0.47	≈ 8.79	≈ 1.28
$I_{2,1}$	–	-	+	–	-	+	≈ 0.24	≈ 9.99	≈ 1.22
$I_{3,1}$	–	–	+	–	-	+	≈ 6.90	≈ 1.18	≈ 1.21
$I_{4,1}$	–	-	+	–	-	+	≈ 0.38	≈ 4.65	≈ 1.19
$I_{5,1}$	–	-	+	–	-	+	≈ 0.06	≈ 4.25	≈ 1.48
$I_{6,1}$	–	–	+	–	-	+	≈ 3.35	≈ 3.78	≈ 1.51
$I_{7,1}$	–	-	+	-	-	+	≈ 0.09	≈ 9.82	≈ 1.12
$I_{8,1}$	–	-	+	-	-	+	≈ 0.34	≈ 1.17	≈ 1.31
$I_{9,1}$	–	-	+	-	-	+	≈ 8.84	≈ 1.47	≈ 1.42
$I_{10,1}$	–	-	+	-	-	+	≈ 0.42	≈ 3.94	≈ 1.23
$I_{11,1}$	–	-	+	-	-	+	≈ 0.28	≈ 3.34	≈ 1.34
$I_{12,1}$	–	-	+	-	-	+	≈ 3.03	≈ 10.0	≈ 1.14
$I_{13,1}$	–	-	+	-	-	+	≈ 0.15	≈ 1.82	≈ 1.11
$I_{14,1}$	–	-	+	-	-	+	≈ 0.42	≈ 4.22	≈ 1.01
$I_{15,1}$	–	-	+	-	-	+	≈ 3.70	≈ 3.55	≈ 1.34
$I_{16,1}$	–	-	+	-	-	+	≈ 0.20	≈ 2.76	≈ 1.32
$I_{17,1}$	–	-	+	-	-	+	≈ 0.08	≈ 1.82	≈ 1.45
$I_{18,1}$	–	-	+	-	-	+	≈ 7.68	≈ 9.15	≈ 1.69
$I_{1,2}$	–	-	+	–	-	+	≈ 0.27	≈ 2.40	≈ 1.54
$I_{2,2}$	–	-	+	–	-	+	≈ 0.73	≈ 1.23	≈ 1.35
$I_{3,2}$	–	-	++	–	-	++	≈ 3.87	≈ 2.41	≈ 1.53
$I_{4,2}$	–	-	+	–	-	+	≈ 0.07	≈ 2.91	≈ 1.35
$I_{5,2}$	–	-	+	–	-	+	≈ 0.25	≈ 3.49	≈ 1.35

Table 4.5 Efficient flexible control for capacity planning decision variables at $\delta = 10\%$ (Cont'd)

Case	Kc_1^{flex}	Kc_2^{flex}	Pc^{flex}	Kr_1^{flex}	Kr_2^{flex}	Pr^{flex}	$\overline{\Delta C}_{Profit}$	$\overline{\Delta C}_{environmental}$	$\overline{\Delta C}_{social}$
$I_{6,2}$	–	-	++	–	-	++	≈ 1.20	≈ 1.12	≈ 1.56
$I_{7,2}$	–	-	+	–	-	+	≈ 0.12	≈ 2.13	≈ 1.36
$I_{8,2}$	–	-	+	–	-	+	≈ 0.37	≈ 1.33	≈ 1.23
$I_{9,2}$	–	-	++	–	-	++	≈ 9.6	≈ 1.19	≈ 1.46
$I_{10,2}$	–	-	+	–	-	+	≈ 0.37	≈ 4.56	≈ 1.35
$I_{11,2}$	–	-	+	–	-	+	≈ 0.03	≈ 1.84	≈ 1.14
$I_{12,2}$	–	-	++	–	-	++	≈ 4.12	≈ 1.58	≈ 1.14
$I_{13,2}$	–	-	+	–	-	+	≈ 0.25	≈ 3.22	≈ 1.44
$I_{14,2}$	–	-	+	–	-	+	≈ 0.03	≈ 1.58	≈ 1.67
$I_{15,2}$	–	-	++	–	-	++	≈ 1.63	≈ 2.18	≈ 1.91
$I_{16,2}$	–	-	+	–	-	+	≈ 0.50	≈ 3.13	≈ 1.23
$I_{17,2}$	–	-	+	–	-	+	≈ 1.03	≈ 1.56	≈ 1.45
$I_{18,2}$	–	-	++	–	-	++	≈ 3.63	≈ 8.40	≈ 1.28

Legend: $\overline{\Delta C}_X$ is the mean percentage of ΔC_X, where X = profit, environmental, and social dimensions

Notation:

–	It has a much lower value than the value proposed by the near-optimal solution
-	It has a lower value than the value proposed by the near-optimal solution
+	It has a higher value than the value proposed by the near-optimal solution
++	It has a much higher value than the value proposed by the near-optimal solution

Table 4.6 Efficient flexible control for capacity planning decision variables at $\delta = 20\%$

Case	Kc_1^{flex}	Kc_2^{flex}	Pc^{flex}	Kr_1^{flex}	Kr_2^{flex}	Pr^{flex}	$\overline{\Delta C}_{Profit}$	$\overline{\Delta C}_{environmental}$	$\overline{\Delta C}_{social}$
$I_{1,1}$	–	-	+	–	-	+	≈ 1.37	≈ 8.39	≈ 2.18
$I_{2,1}$	–	-	+	–	-	+	≈ 1.34	≈ 9.19	≈ 2.22
$I_{3,1}$	–	–	+	–	-	+	≈ 12.90	≈ 1.38	≈ 2.18
$I_{4,1}$	–	-	+	–	-	+	≈ 1.38	≈ 4.45	≈ 2.19
$I_{5,1}$	–	-	+	–	-	+	≈ 1.36	≈ 4.25	≈ 2.11
$I_{6,1}$	–	–	+	–	-	+	≈ 6.35	≈ 3.38	≈ 2.51
$I_{7,1}$	–	-	+	-	-	+	≈ 1.10	≈ 9.42	≈ 2.18
$I_{8,1}$	–	-	+	-	-	+	≈ 1.24	≈ 1.27	≈ 1.99
$I_{9,1}$	–	-	+	-	-	+	≈ 12.84	≈ 1.27	≈ 2.43
$I_{10,1}$	–	-	+	-	-	+	≈ 1.12	≈ 3.34	≈ 2.67
$I_{11,1}$	–	-	+	-	-	+	≈ 1.48	≈ 3.44	≈ 2.56
$I_{12,1}$	–	-	+	-	-	+	≈ 9.03	≈ 1040	≈ 2.11
$I_{13,1}$	–	-	+	-	-	+	≈ 1.51	≈ 1.32	≈ 2.00
$I_{14,1}$	–	-	+	-	-	+	≈ 2.12	≈ 4.43	≈ 1.99
$I_{15,1}$	–	-	+	-	-	+	≈ 7.70	≈ 3.25	≈ 1.99
$I_{16,1}$	–	-	+	-	-	+	≈ 1.21	≈ 2.36	≈ 2.34
$I_{17,1}$	–	-	+	-	-	+	≈ 1.38	≈ 1.42	≈ 2.10
$I_{18,1}$	–	-	+	-	-	+	≈ 14.68	≈ 9.25	≈ 1.95
$I_{1,2}$	–	-	+	–	-	+	≈ 1.23	≈ 2.40	≈ 2.63
$I_{2,2}$	–	-	+	–	-	+	≈ 1.33	≈ 1.43	≈ 2.45
$I_{3,2}$	–	-	++	–	-	++	≈ 12.87	≈ 2.21	≈ 1.89
$I_{4,2}$	–	-	+	–	-	+	≈ 1.07	≈ 2.11	≈ 2.48
$I_{5,2}$	–	-	+	–	-	+	≈ 2.38	≈ 3.19	≈ 2.56

Table 4.6 Efficient flexible control for capacity planning decision variables at $\delta = 20\%$ (Cont'd)

Case	Kc_1^{flex}	Kc_2^{flex}	Pc^{flex}	Kr_1^{flex}	Kr_2^{flex}	Pr^{flex}	$\overline{\Delta C}_{Profit}$	$\overline{\Delta C}_{environmental}$	$\overline{\Delta C}_{social}$
$I_{6,2}$	–	-	++	–	-	++	≈ 7.20	≈ 1.32	≈ 2.36
$I_{7,2}$	–	-	+	–	-	+	≈ 2.12	≈ 2.43	≈ 2.36
$I_{8,2}$	–	-	+	–	-	+	≈ 1.37	≈ 1.43	≈ 1.93
$I_{9,2}$	–	-	++	–	-	++	≈ 15.6	≈ 1.19	≈ 2.11
$I_{10,2}$	–	-	+	–	-	+	≈ 3.23	≈ 4.46	≈ 2.34
$I_{11,2}$	–	-	+	–	-	+	≈ 1.00	≈ 1.24	≈ 2.00
$I_{12,2}$	–	-	++	–	-	++	≈ 9.09	≈ 1.48	≈ 1.89
$I_{13,2}$	–	-	+	–	-	+	≈ 1.15	≈ 3.52	≈ 2.34
$I_{14,2}$	–	-	+	–	-	+	≈ 2.13	≈ 1.68	≈ 1.88
$I_{15,2}$	–	-	++	–	-	++	≈ 3.63	≈ 2.38	≈ 1.91
$I_{16,2}$	–	-	+	–	-	+	≈ 1.50	≈ 3.23	≈ 1.84
$I_{17,2}$	–	-	+	–	-	+	≈ 1.21	≈ 1.26	≈ 1.99
$I_{18,2}$	–	-	++	–	-	++	≈ 12.63	≈ 8.30	≈ 2.14

Legend: $\overline{\Delta C}_X$ is the mean percentage of ΔC_X, where $X =$ Profit, Environmental and Social

Notation:

–	It has a much lower value than the value proposed by the near-optimal solution
-	It has a lower value than the value proposed by the near-optimal solution
+	It has a higher value than the value proposed by the near-optimal solution
++	It has a much higher value than the value proposed by the near-optimal solution

Chapter 5 Product Lifecycle on Reverse Logistics Social Responsibility

5.1 Introduction

The concept of social responsibility in this chapter is proposed by looking at both company and consumer in the supply chain as entities that are organisms (Caruana and Chatzidakis, 2013; Lozano et al., 2014). Corporate Social Responsibility (CSR) is conducted by companies because of their production and transportation activities. In contrast, Consumer Social Responsibility (CnSR) is conducted by consumers because of their consumption activities. So, both companies and consumers perform social responsibility in the supply chain due to the impact of their activities, which influence both the environment and society (Caruana & Chatzidakis, 2013). One of the good example of real world practice that comparable to social responsibility concept in this chapter is the automotive related recycling in Japan by the Japanese Ministry of the Environment (www.env.go.jp). For that reason, Reverse Logistics Social Responsibility (RLSR) is one of the most preferred social responsibility activities in the supply chain as discussed in Chapter 3. RLSR is the type of reverse logistics that is conducted in the supply chain as a voluntary integrated social responsibility activity. It involves most of the actors who have an impact on the supply chain social responsibility from supplier to consumer (Ciliberti et al., 2008b). Involving as many actors as possible in the supply chain becomes critical since social responsibility performance among actors affects others' performances (Cruz, 2013; Formentini and Taticchi, 2014).

Economic, environmental, and social dimensions are the basic foundation of sustainability (Elkington, 1999). Earlier research has shown that RLSR enables actors to achieve sustainability (Nikolaou et al., 2013). It assumes that each sustainability dimension is independent. In contrast, there is a newer issue about the interaction among sustainability dimensions (Lozano et al., 2014; Seuring, Sarkis, Müller, & Rao, 2008b). The issue brings us to the idea that by considering the trade-off among sustainability dimensions, the interrelated benefits and disadvantages of each sustainability dimension could be advanced. Related to the social responsibility issue in the supply chain, interrelated issues could give a clear answer to the important question of how economic return could emerge from social responsibility (Ciliberti et al., 2008a).

The capacity planning in reverse logistics involves complex issues (Georgiadis & Athanasiou, 2010). The uncertainties inherited from the reverse logistics due to the variability of a product's usage period, along with the unknown reusability, the breakdown rate, and the recycling rate of the used products, make the decision-making process about the capacity policies a difficult task to accomplish. The decision to either expand or contract capacity is associated with important questions that need to be answered, such as when, where, and how much to expand/contract. In addition, the length and patterns of a product's lifecycle, as well as the volume and timing of returns which can be reused to satisfy new demand, make the difficulties much greater.

Unlike the capacity planning in common reverse logistics, the capacity planning in RLSR is more complex. As reverse logistics is a social responsibility activity, the decision to either expand or contract is now constrained by the existence of a social responsibility fund that is generated from the premium price that is contributed by consumers (Hsueh & Chang, 2008; Sudarto et al., 2014). So, the capacity planning in RLSR has additional constraints compared to common reverse logistics. Moreover, by considering the interrelated sustainability dimensions in RLSR that produces a unique relationship between sustainability dimensions, uncertainty, and the policy. Therefore, the capacity planning in RLSR becomes much more than a trivial exercise.

The aim of this chapter is to analyze the impact of capacity planning on the product lifecycle for performance on sustainability dimensions in RLSR by using a System Dynamics (SD) approach. A single-product SD approach is used since the supply chains in this study are complex and the system under study is dynamic and has limited feedback. So, the SD approach is preferred in comparison to optimization to avoid the occurrence of infeasible solutions (Hsueh, 2014; Bhattacharjee & Cruz, 2015; Golroudbary & Zahraee, 2015). Here, the developed efficient flexible capacity planning (Georgiadis & Athanasiou, 2013; Vlachos et al., 2007) works together with a social responsibility level policy (Hsueh & Chang, 2008) to tackle the product lifecycle with its inherited uncertainties such as the product lifecycle length (L), return patterns (P), and residence index (RI). These uncertainties entail a higher risk of shortage in end-of-use product returns, since supply may vary and the volume to be dismantled may turn out to be lower than predicted. This will cause the overcapacity phenomenon in capacity planning, which may negatively affect the profitability in the long run, especially in the high-capacity acquisition condition (Georgiadis & Athanasiou, 2013). In capacity planning, the term "efficient" refers to the allocation of a limited supply of a social responsibility fund, while the term "flexible" refers to the adaptability for tackling the lifecycle with its inherited uncertainties (Bai & Sarkis, 2013). So, efficient, flexible capacity accommodates the need to become adaptable to uncertainty with a limited social responsibility fund.

Last, the interrelated sustainability dimensions are measured to see the policy impacts. The Taguchi design of experiment is used (Antony, 2003; Ramachandran & Tsokos, 2015). The product lifecycle with its inherited uncertainties is assigned as the noise factors. The policy parameters are assigned as control factors and the three sustainability dimensions are measured as the key performances. The goal is to find the policy effect on the model performance that is affected by uncertainty noise. In the end, the significance with its power is measured to show the power of the relationship between policy and the uncertainty for the sustainability dimensions performance. So, it deals with the important question of how the interrelated sustainability dimensions are impacted by the capacity planning in the product lifecycle in RLSR.

Previously, the research about analyzing the impact of behavior in RL due to product lifecycle with inherited uncertainty has been conducted by Georgiadis et al. (2006) and Georgiadis and Athanasiou (2010). Both of research groups focus on capacity planning as the key policy parameters for dealing with considered product lifecycle parameters. Since there is a close relationship between complex issues in the capacity planning that explained in the fourth paragraph in this section and product lifecycle, e. g. the case of Pack2-pack (Georgiadis and Athanasiou, 2013) shows that capacity planning in reverse channel of Closed-Loop Supply Chains (CLSCs) can impact the lifecycle of product families produced in the forward channel. However, unlike those two research groups, the proposed model considers the uncertainties as noise factors instead of control factors. The second research group assigns cost and time parameter settings as its noise factors. Besides, almost identically to the design in this study, the first research group sets fixed values for the cost and time parameters and focuses on the effect of specific lifecycle characteristics on the optimal capacity planning policy. So in brief, a difference exists because the goal of this paper is to find a significant effect of the policy on performance in the model of the supply chain with RLSR that is affected by uncertainty noise (Sudarto, Takahashi, & Morikawa, 2016). Therefore, it satisfies the terminology of the Taguchi design of experiment (Antony, 2003).

The paper is structured into the following sections. After the introduction, the second section discusses the seminal works on social responsibility in the supply chain literature. The third section discusses our SD model of RLSR. Section four discusses the experimental design. Section five presents a discussion of the results obtained. Finally, the conclusions and possible future extensions of the research will be discussed in section six.

5.2. Social Responsibility in the Supply Chain

There are complex relationships between social responsibility, risk, and profit in the supply chain (Cruz, 2013). First, the risk consists of supply-side disruption risk, social risk, and demand-side uncertainty. Second, profit refers to not only economic effects but also customer loyalty through reputation. Third, poor social responsibility performance by any player in the supply chain may damage the focal firm's reputation, such as in the cases of McDonalds, Mitsubishi, Monsanto, Nestlé, Nike, Shell, and Texaco. These relationships have the consequence that for some actors, social responsibility becomes a cost, while other actors earn social responsibility benefits. So, the actors need to work together to share the mutual risk and profit.

Social Responsibility Streams in the Supply Chain

The classical social responsibility perspective is that social responsibility is an act of charity that acts for a specific firm purpose (Gilberthorpe & Banks, 2012). However, the newer perspective is that social responsibility is an incentive to act together among actors in the supply chain to create additional revenue and benefits (Caruana & Chatzidakis, 2013; Hsueh, 2014). Unfortunately, the newer perspective can only exist by involving the consumer in the supply chain as the strategic key to social responsibility with the additional benefits of reducing risk on the demand side. Companies and consumers in the supply chain have different motivations for performing social responsibility. Companies consume resources for producing and transporting products. On the other hand, consumers are responsible because they consume the products, which could damage the environment, society, or both after their consumption period.

Accordingly, over the last 50 years, social responsibility in the supply chain has changed from involving a single corporation to involving multiple companies (Maloni & Brown, 2006). The empirical data show that social responsibility in the supply chain can be divided into five main streams (Ciliberti et al., 2008b), namely:

f. Purchasing Social Responsibility (PSR), which is purchasing while considering social issues;
g. Sustainable Transportation (ST), which is carrying out transportation while preserving social justice now and for the future;
h. Sustainable Packaging (SP), which is packaging the product in such a way as to add value to society and environment;
i. Sustainable Warehousing (SW), which is warehousing while considering benefits to the local community;
j. Reverse Logistics Social Responsibility (RLSR), which is related to the reduction of resource use, recycling, substitution, reuse, and disposal of materials.

Actors with an Impact on Social Responsibility in the Supply Chain

The actors in the supply chain need to work together regarding mutual risk and profit. Consequently, the impact on the supply chain performance of the role played by each actor with an impact on social responsibility in the supply chain must be carefully considered. Some examples of considerations made in playing these roles are as follows (Cruz, 2013; Georgiadis & Besiou, 2008):

a. The supplier is a supply side social license holder. The supplier needs to ensure the supply of raw materials or any natural resources. One of the key issues of this important role is maintaining social stability in the area where the natural resources are exploited or raw materials are produced.
b. The manufacturer is the center of the cost–benefit tradeoff of social responsibility. The manufacturer is the actor who mostly experiences the cumulative benefits and disadvantages of the social responsibility issue.

c. The distributor promotes social responsibility to the end customer. It creates a bridge to transfer the value of social responsibility generated by the corporation to the consumer.
d. Customers are key to the success of the supply chain social responsibility. Products consumed by consumers make a statement about them (Griskevicius, Tybur, & Van den Bergh, 2010). So their awareness and acceptance of social responsibility products are keys to the success of social responsibility in the supply chain.
e. The legislator produces social responsibility legislation in the supply chain. Legislators are gatekeepers who maintain the sustainability of economic, environmental, and social returns at macro-level. Therefore, they are important stakeholders to be considered.

The focus is on increasing the number of actors with an impact on social responsibility who are involved. So combining the above streams is not preferred, since it increases only the complexity of the activity but not the number of actors; for example, PSR is performed by the supplier and manufacturer (Carter & Jennings, 2002), both of which are already involved in RLSR. Thus, RLSR is preferred because it involves more actors with impact compared to the other streams. In addition, RLSR promotes recycling, reuse, and resource conservation and addresses various aspects of social sustainability (Nikolaou et al., 2013; Sarkis et al., 2010).

Reverse Logistics Social Responsibility

A comparison of the features of the proposed model and previous research is shown in **Table 5.1**. The number of research articles on social responsibility issues is relatively limited (Govindan et al., 2014; Hsueh, 2015), especially in CLSCs. Therefore, the selected papers in **Table 5.1** for selecting the benchmark model in this chapter are based on those research articles closest to the research in this chapter that, to the best of the authors' knowledge, can be found. As shown in **Table 5.1** except for Hsueh and Chang (2008), the benchmark models have at least two fundamental similarities. First, the benchmark models have CLSCs networks that produce as-good-as-new products. Second, it consists of collection and recycling operations in the reverse channel.

From the table, it can be seen that the features of the proposed model are closely related to those in Chapter 3, but with significant differences in product lifecycle, trade-off, and capacity planning. The proposed model features are developed by following the four essential steps of theoretical thinking. First, Hsueh and Chang (2008) proposed a mathematical model proof of the relationship between levels of social contribution in the supply chain, which affects the economic dimension of the total supply chain. Their drawback about social responsibility fund that comes from the premium price that is paid by the consumer delivers one of many possible answers on where the money for performing social responsibility comes from and how the corporate-consumer social responsibility should be met. The fund is strongly related to the trade-off between sales loss due to increased price and increased sales due to improved reputation due to performing social responsibility activities. They also argue that the "virtual social responsibility benefits" – the virtual benefits that are earned by performing a social responsibility, for example, social license, good reputation, and so on – could be assumed to be equivalent to the money spent on social responsibility. However, they are not measuring social performance in their research. So they fail to answer the important question of where the money in the social responsibility fund should be invested and how the social responsibility reputation that increases sales is gained. Their failure in answering such important question is then satisfied as discussed in Chapter 3.

Second, Chapter 3 proposed that the fund should be invested in RLSR to balance the share of mutual risk and profit from social responsibility. At the same time, the invested fund could create a green image — the environmental dimension — which would drive an increase in demand. Also, he measures the social dimension performance as the ratio of the invested fund to the economic loss/gain. This is the reason why the proposed model features such as the social responsibility fund, sales loss, and social contribution levels policy are taken from their model. However, unlike his model, here the model proposes a cumulative green image and then changes the term “green image” to “environmental dimension performance” and the net present value of “social benefits” to “social dimension performance” for dealing with product lifecycle issues. Since the social responsibility fund and sales are strongly related to the product lifecycle, studying the performances of one cycle of the product lifecycle will be enough. That is why the proposed model considers a single product rather than multiple products like Georgiadis and Athanasiou (2013).

Third, it is necessary to consider economic, environmental, and social dimensions in RLSR or social responsibility in general. This highlights the issue of social responsibility in the supply chain, which comes with a complicated definition. Since social responsibility itself has no standard in either the academic or the practical area (Gilberthorpe & Banks, 2012), the scope of social responsibility activity itself becomes unclear. Nevertheless, there are two definitions of social responsibility that are most acceptable and are adopted nowadays. The first definition is adopted by the European Union (EU), which argues that environmental and social aspects must be fulfilled by voluntary social responsibility (Ciliberti et al., 2008b). In contrast, the second definition is self-defined by the social responsibility actors (Baden et al., 2009). Here, the first definition is preferred to avoid “green and social wash” issues produced by the second definition. For this reason, the first definition is adopted in RLSR research (Nikolaou et al., 2013). So, in accordance with this definition, social responsibility needs to consider and achieve performance on the economic, environmental, and social dimensions simultaneously.

However, after these three dimensions for achieving sustainability (Elkington, 1999) through social responsibility have been acted on, there is still another issue concerning the relationship between the sustainability dimensions. Thus in RLSR, interrelated dimensions in Chapter 3 are preferred to non-interrelated ones (Nikolaou et al., 2013) for measuring policy performance effectiveness, since the interrelated dimensions could advance the understanding of win–win and trade-off situations of the relation between the three dimensions of sustainability (Seuring et al., 2008b).

Fourth, since by definition social responsibility is driven by voluntary motivation, our RLSR model adopts an ecological motivation feature. This feature is taken from Georgiadis and Besiou (2008) and in Chapter 3 to see how voluntary motivation drives the collection and recycling activity. However, unlike Vlachos et al. (2007) and in Chapter 3, the proposed model accommodates not only capacity expansion but also capacity contraction, since our total demand pattern refers to the product lifecycle pattern from introduction to decline.

Table 5.1 Features comparison of research in reverse logistics and reverse logistics social responsibility

References	Approach	Focus	Sustainable Dimensions			Lifecycle	Product(s)	Trade-off	Policy
			Economic	Environmental	Social				
Georgiadis et al., 2006	SD	Impact of behavior	√	–	–	Full	Single	Lifecycle; patterns	Early stage CP
Vlachos et al., 2007	SD	Developing efficient CP	√	–	–	Limited	Single	Ecological motivation	Efficient CP
Georgiadis and Besiou, 2008	SD	Impact of behavior	√	√	–	Limited	Single	Ecological motivation; technological motivations	–
Hsueh and Chang, 2008	OR	Social to economic mathematical model	√	–	√	Not considered	Single	Social responsibility fund; sales loss	Social responsibility contribution level
Georgiadis and Athanasiou, 2013	SD	Developing flexible CP	√	–	–	Full	Multiple	Lifecycle; patterns; residence index; quality level of used products	Flexible CP
Chapter 3	SD	Sustainable RLSR SD model	√	√	√	Limited	Single	Social responsibility fund; sales loss; ecological motivation	Social responsibility contribution level and efficient CP
Proposed model	SD	Impact of behavior	√	√	√	Full	Single	Social responsibility fund; sales loss; ecological motivation; lifecycle; patterns; residence index;	Social responsibility contribution level and efficient, flexible CP

Abbreviations: CP = Capacity Planning; OR = Operations Research; RLSR = Reverse Logistics Social Responsibility; SD = System Dynamics

Last, in short, The proposed model extends the RLSR SD model of Chapter 3 by adopting some improvements from two research groups, namely Georgiadis et al. (2006) for product lifecycle with its inherited uncertainty feature and Georgiadis and Athanasiou (2013) for flexible capacity planning feature. Thus, the results of the impact of behavior on sustainability dimensions in my model will be benchmarked to both research groups. So, this chapter will contribute to the relatively limited academic knowledge on the analysis of the impact of behavior in reverse logistics. It extends the insights of both research groups. However, the focus is placed on the social responsibility aspect of reverse logistics for sustainability by considering the fixed-cost parameter settings and interrelated sustainability dimensions. Here Georgiadis and Athanasiou (2010) is not included since they have the same product lifecycle with its inherited uncertainty feature like Georgiadis et al. (2006) that needed in this chapter.

5.3 System Dynamics Model of Reverse Logistics Social Responsibility

A Causal Loop Diagram (CLD) is a part of SD model validation (Sterman, 2002) and builds confidence in the model (Barlas, 1996; Forrester & Senge, 1979). Differently, a Simplified Causal Loop Diagram (SCLD) shows only the most important loops in the model. The most common emblematic form of the enhanced box is ended by the word "RULE", for example, Production and Distribution RULE. **Fig. 5.1** shows the proposed model SCLD, and the simulation is built by using Anylogic software. It consists of four main loops: two balance loops (B1 and B2) and two reinforcement loops (R1 and R2), comparable to Sudarto et al. (2014). The R1 reveals that the SD model is considered as a pull system where demand drives production. The *Demand* and product lifecycle, with its inherited uncertainties, fit in the Consumer RULE. B1 represents how demand (*Demand*) decreases as the social responsibility contribution level (*SR_Level*) increases: price (*Price*) increases to the premium price (*Premium_Price*), which then causes a loss of *Demand*. This process produces a social responsibility fund (*SR_Fund*) that will be used for financing RLSR. This loop adapts the mathematical model of a *Price* increase that limits *Demand* (Feng, Wang, & Chen, 2014; Hsueh & Chang, 2008), but it is improved by adding *Demand* recovery and *Demand* improvement features. This causes the model to reinforce the *Demand* after the RLSR activity that is financed by the SR_Fund is conducted, leading to good environmental performance. This loop is represented by R2. Then, B2 indicates that incompliance with legislation (*Legislation*) will damage the supply chain economic performance (*Total_Supply_Chain_Profit*) (Georgiadis & Besiou, 2008). Thus, policy makers should carefully consider their policy since there is a trade-off between *Demand* loss and the *Demand* improvement process with the need to comply with legislation (*Legislation_Compliance*) standards with the existence of penalties (*Penalty*). However, unlike in Chapter, the product lifecycle with its inherited uncertainties is now being considered. Accordingly, the capacity planning changes to long-term, efficient, and flexible to tackle this issue with expansion and contraction options to further advance the economies of scale. Also, there are some modifications in the sustainability dimensions performance measurement to accommodate the needs of capacity planning policy to become efficient and flexible.

In addition, **Fig. 5.2** gives a clearer description about the CLD in the system under the study. It shows more SD model entities that correspond to real world entities, unlike **Fig. 5.1**. While **Fig. 5.1** is built to show the most important loops in the system simply, **Fig. 5.2** is built to show the system complexity itself, including the relationship between CLD and the most closely related papers. As shown in **Fig. 5.2**, the base of the SD model supply chain is mainly built upon the two most closely related papers – including the data of the model – namely (Vlachos et al., 2007) and (Georgiadis & Besiou, 2008). The social responsibility RULE is developed based on Chapter 3. In addition, the capacity planning is proposed in this chapter, but the data for the product lifecycle with its inherited uncertainties are taken from (Georgiadis et al., 2006). So here, the model adopts secondary data, except for the data in **Fig. 5.3** and **Eq. (5.1)**, that are hypothetically generated. But even though both functions' data are hypothetically generated, the concepts of the functions themselves are adopted from the previous research (Georgiadis & Besiou, 2008; Griskevicius et al., 2010; Hsueh & Chang, 2008).

The research on social responsibility issues especially in CLSCs is important as discussed in Section 2. But unfortunately there are relatively few research articles discussing this issue, especially using a quantitative approach (Govindan et al., 2014; Hsueh, 2015). Therefore, the selected papers in **Table 5.1** for selecting the benchmark model in this chapter are based on those research articles closest to the research in this paper that, to the best of the authors' knowledge, can be found.

The works of Georgiadis and Besiou (2008) and Vlachos et al. (2007) are the basis of RLSR SD model in Chapter 3 that is used as the major reference in this chapter. The model of the first research group proposes how ecological motivations influence the reverse logistics economic performance. Their model is adopted in B2 and R1, since it represents how reverse logistics capability complies with Legislation through ecological motivation to avoid penalties. But, because the collection capacity (*COLLECTION_CAPACTY*) and the recycling capacity (*RECYCLING_CAPACITY*) are assumed to be static in their model, the environmental dimension (*Green_Image* = *GI*) will always be constant. Also, social performance (*Social_Performance*) is not measured. So, no economic return on social responsibility could be advantaged. Such limitations are overcome in our model by adding an additional feature: dynamic, long-term, efficient, flexible capacity planning and social performance measurement. On the other hand, the second research group proposed a theoretical mechanism of efficient capacity planning in the SD approach. Their model is adopted in R1 since the actors involved are the same as the actors with an impact on social responsibility in the supply chain, and both groups of actors are performing the same activity: reverse logistics. But since they are not considering the source of funding to finance reverse logistics, limitless capacity planning could be considered in their SD model. In addition, no social performance is measured, so the economic return on social performance could not be examined. Therefore, this limitation is overcome by limiting the capacity planning policy with the existence of the *SR_Fund*. In addition, since they are not considering the full product lifecycle, they only have the expansion option in their capacity planning. In contrast, in this study the capacity planning has expansion and contraction options for dealing with the full product lifecycle.

So both models have two identical fundamental similarities. First, they consist of CLSC networks that produce as-good-as-new products. Second, they consist of collection and recycling activities. However, there is a slight difference in the term "as-good-as-new single product" between the two models. Vlachos et al.'s (2007) reverse channel produces the *SERVICEABLE_INVENTORY* (Recycled New Products), while Georgiadis and Besiou's (2008) reverse channel produces the *RM_INVENTORY* (Recycled Raw Materials). So that is why the first researchers used the terminology "Remanufacturing" and the second used "Recycling". However both of them have the same framework in their SD models for forward and reverse channels. So this key similarity is used in this paper's model. In addition, since this chapter focuses on producing recycled new materials as shown in **Appendix A**, the term "Recycling" is used rather than "Remanufacturing".

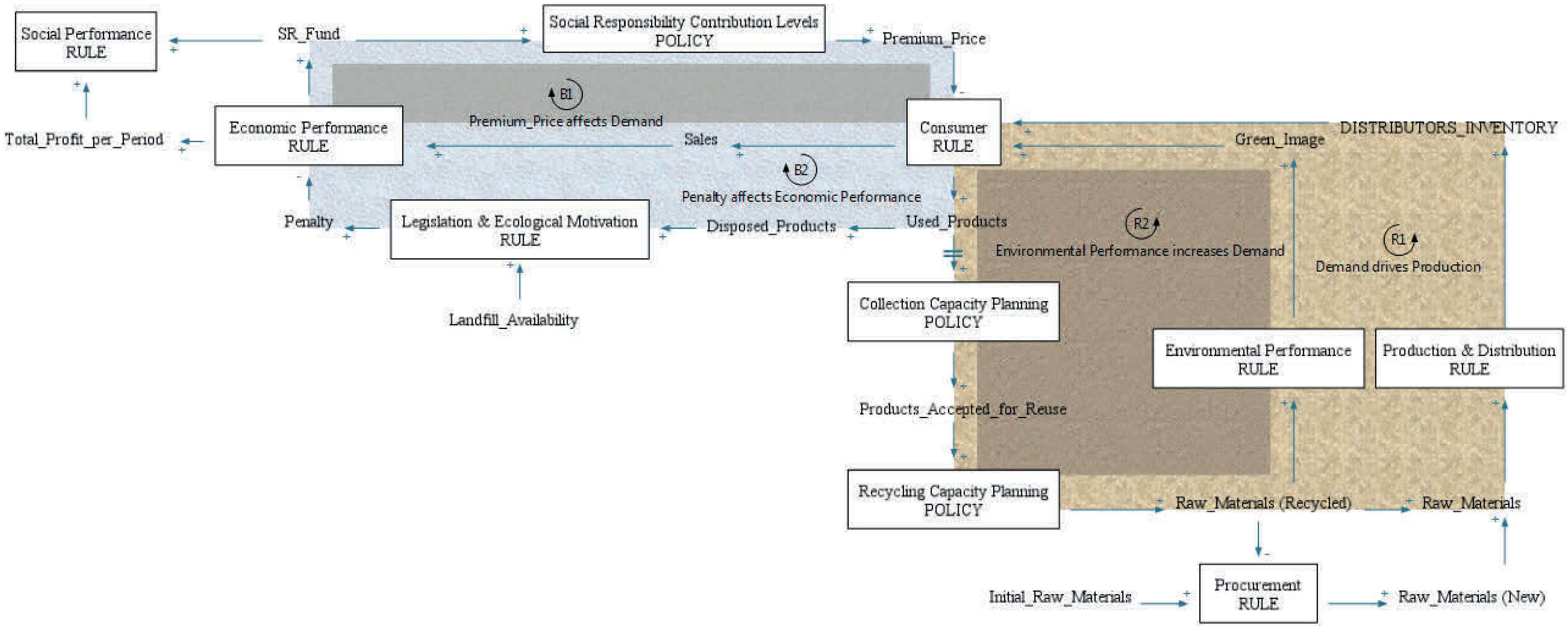

Fig. 5.1 Simplified causal loop diagram of supply chain with reverse logistics social responsibility

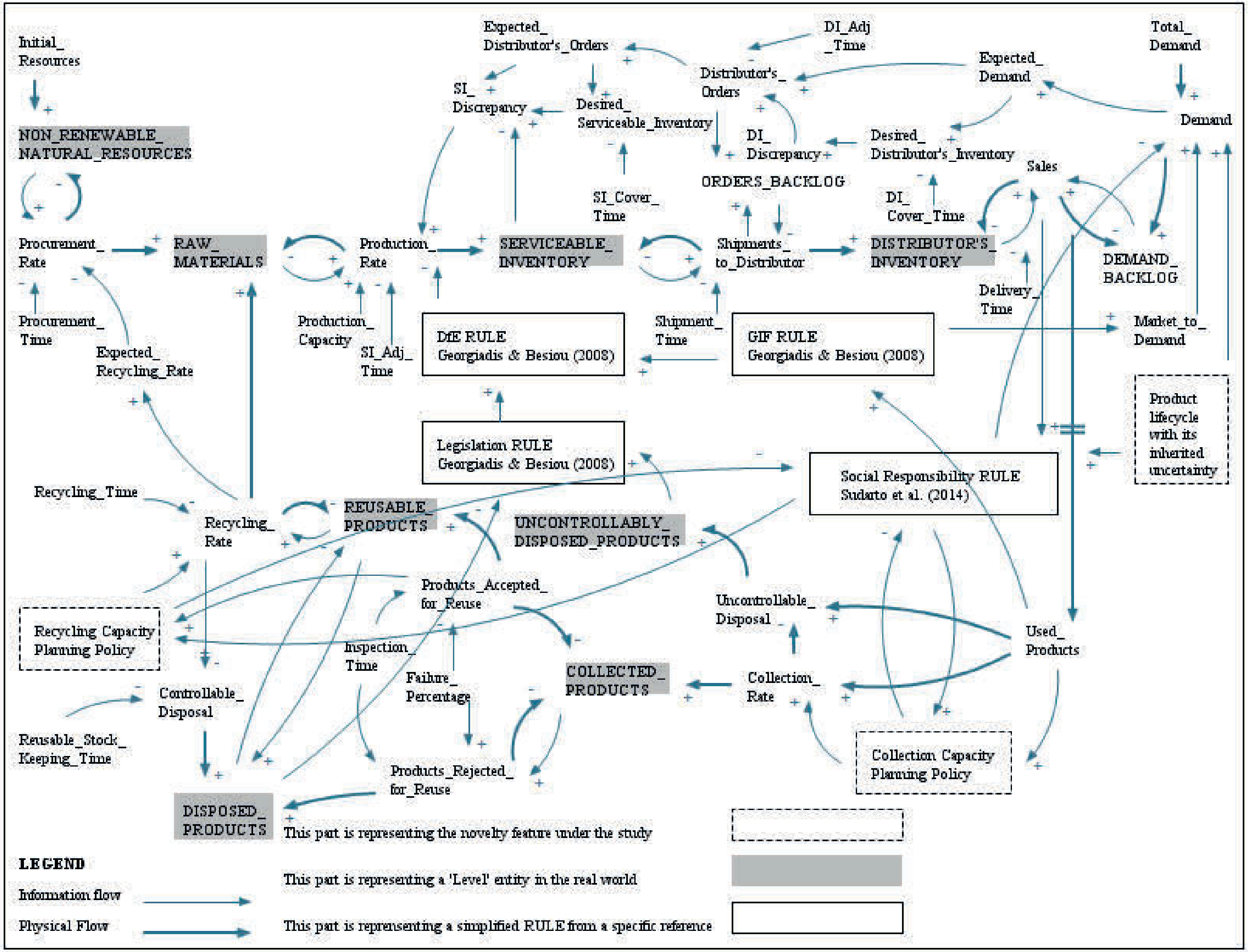

Fig. 5.2 Causal loop diagram of supply chain with reverse logistics social responsibility

In contrast, there are four keys differences between their models (Vlachos et al., 2007; Georgiadis and Besiou, 2008) to the research needs in this chapter. These differences make their basis model needs to be improved here such as: first, the adoption of the social responsibility perspective; second, the use of interrelated sustainability dimensions performance measurement; third, the use of an efficient flexible capacity planning policy; and last, the consideration of product lifecycle with its inherited uncertainties.

Then, as mentioned in **Sections 5.1** and **5.2**, the policy options in the model consist of (1) the social responsibility policy (*SR_Level*) and (2) the capacity planning policy (*COLLECTION_CAPACITY* and *RECYCLING_CAPACITY*). In this chapter, the policy parameters are simplified, as will be explained in Section 4. According to **Fig. 5.1**, the first policy refers to the Social Responsibility Contribution Levels POLICY and the rest of the policies refer to the Collection Capacity Planning POLICY and Recycling Capacity Planning POLICY.

The first policy is represented by the *SR_Level* constant in the SD model with a dimensionless unit (Hsueh & Chang, 2008). *SR_Level* refers to how much the *Price* will be increased to reach the *Premium_Price*. The range of policy values is set between 0 and 1, where 0 means no social responsibility is performed in the supply chain so there is no *Price* increase while 1 means that social responsibility is performed in the supply chain – RLSR – with a doubling of the price. In the end, this policy will adjust the *Demand* loss but the supply chain will start to provide the *SR_Fund* to finance RLSR activity. The assumption in Consumer RULE is that the *Demand* loss will be adjusted based on the consumer segmentation. The segments range from high social responsibility sensitivity – willingness to buy more expensive products in exchange for social responsibility value – to low social responsibility sensitivity. Each segment has its own range of threshold values for price increases to maintain its *Demand*.

Unlike the first policy, which is used to adjust the Price to earn *SR_Fund* to achieve optimal economic and social performance results, the other policy is used to adjust RLSR capacity planning for optimal usage of the *SR_Fund* to obtain optimal environmental performance. The collection capacity planning policy is represented by $Pc, K_{C_1},$ and K_{C_2} in the SD model, with Pc being expressed in weeks and K_{C_1} and K_{C_2} being dimensionless. Pc represents the length of the review period for *COLLECTION_CAPACITY* expansion (Vlachos et al., 2007) and contraction, with the range of the policy being from 1 to *n*, where 1 refers to frequent review, which is adopted in inefficient capacity planning (e. g. Georgiadis and Athanasiou, 2013), and *n* refers to less frequent review. Larger values of *n* will produce higher savings from economies of scale but will decrease the flexibility of capacity planning. Economies of scale are the core of our cost structure assumption in the capacity planning, where a larger increment of capacity produces a lower cost of unit-based capacity expansion (Georgiadis & Athanasiou, 2010; Georgiadis et al., 2006). Then, K_{C_1} and K_{C_2} represent the control variables of proportionality of expansion and contraction for *COLLECTION_CAPACITY* (Georgiadis & Athanasiou, 2013), where the range of policies could be from 1.0 to 3.0, where 1.0 refers to less aggressive capacity expansion and 3.0 refers to aggressive capacity expansion. In the end, this policy will adjust the actual value of the *COLLECTION_CAPACITY*. The recycling capacity planning policy has the same structure as the second policy, but it is used for *RECYCLING_CAPACITY* building and is represented by $Pr, K_{r_1},$ and K_{r_2}. So, in short, both of the policies are adopted from Vlachos et al. (2007) to achieve efficiency and Georgiadis and Athanasiou (2013) to achieve flexibility in the capacity planning policy. Then, they are revised so that they are aligned with the first policy to make sure that the capacity planning can receive enough support from the social responsibility fund.

Fig. 5.3 and **Eq. (5.1)** are the key to the novelty features function that is used in the system under study. First, the illustration in **Fig. 5.3** represents how each market segment reacts to premium price. This function belongs to *MR_Results* in Social Responsibility RULE in **Fig. 5.1**.

There are four market segments in the function based on arrays of *MARKET_COMPOSITION* (see **Appendix A**), namely 1: Low (LS) to 4: High (HS). The low sensitivity market segment is highlighted by the same increment of price to premium price (*SR_Level*), which will cause more consumers to not buy the product compared to the highly sensitive market segment. So each market segment responds differently by either buying or not buying the product depending on the size of the price increase up to the premium price (Griskevicius et al., 2010; Hsueh & Chang, 2008). So in simplified, **Fig. 5.3** shows the simplified relationship of the *Market_Response* results for each *MARKET_COMPOSITION* due to *SR_Level*. Second, the function **Eq. (5.1)** represents how much the demand is shifting due to the increase of environmental performance. That is why **Eq. 1** is strongly related to the GIF (Green Image Factor) RULE as shown in **Fig. 5.1** (Georgiadis & Besiou, 2008). So, put simply, **Fig. 5.3** represents the demand elasticity in the system and **Eq. (5.1)** represents the scale of the impact because of the relationship between sustainability dimensions. So both have a great impact on the system settings in this study, since one of them is the key to the social responsibility elements to generate the social responsibility fund and the other is the key to interrelated sustainability dimensions in this study.

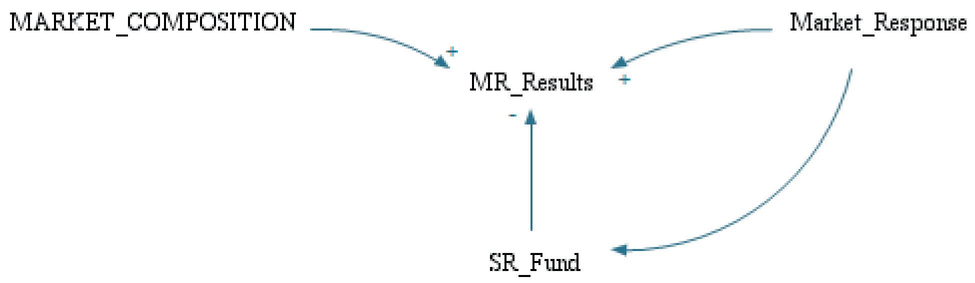

Fig. 5.3 Simplified illustration on how each market segment (MR_Results) reacts to premium price (SR_Fund)

$$Demand = Total\_Demand \times (1 + Market\_to\_Demand) \tag{5.1}$$

Lastly, the SD model will be run to carry out the simulation and the dimensions of the performance are used for policy effectiveness with the relationship between performance dimensions as shown in **Fig. 5.1**. The performances will be measured in sequence as follows. First, the economic performance will be measured. Second, the social performance based on the economic return from RLSR activity will be measured. Lastly, the environmental performance will be measured as a result of RL activity. Detailed information on the measured performance dimensions is given below:

a. Economic dimension performance

   The equation is written as shown in **Eq. (5.2)** that similar to **Eq. (4.17)**.

b. Environmental dimension performance

   This is represented by the variable *GI*, which is defined as the cumulative change in green image produced by RLSR activity, with a dimensionless unit. The equation is written as shown in **Eq. (5.3)**. It comes from the collective result of the change in green image per period. The range of values is between 0 and $+\infty$.

c. Social dimension performance

   This is represented by the function shown in **Eq. (5.3)** similar to **Eq. (4.19)**

$$\text{Total\_Supply\_Chain\_Profit} = \text{npv}\ (\text{Total\_Profit\_per\_Period}, \text{Discount\_Factor}, 0, 1, 0.01)$$

(5.2)

$$\text{GI}(t) = \int_0^t (\text{Periodic\_GI}) \times dt$$

(5.3)

$$\text{Social\_Performance}(t) = \int_0^t (\text{SR\_Fund} = 0?\ 0: \text{Total\_Profit\_per\_Period} \times (\text{SR\_Spending\_Rate}/\text{SR\_Fund})) \times dt$$

(5.4)

In detail, the social responsibility contribution levels refer to Chapter 3. However, unlike their model, the details of the control-theory-based capacity planning policy mechanism used in this model are as illustrated in **Fig. 5.4**. **Figure 5.4** shows the CLD of the recycling capacity planning control mechanism for efficient, flexible capacity planning. The model has a synergetic feature of efficiency, taken from the research group Vlachos et al. (2007), and flexibility, taken from Georgiadis and Athanasiou (2013). The efficiency refers to *Pr* or the review period of capacity planning that is contained in *RC_Discrepancy*. Therefore, the early stage expansion and frequent reviews that exist in the flexible model of the second research group could be avoided. So, unused capacity generated by early stage expansion is avoided. On the other hand, K_{r_1} and K_{r_2}, or the proportions of expansion and contraction, are adopted from the second research group, whereas the first research group only have an expansion policy. Both decision variables belong to *RC_Expansion_Rate* and *RC_Contraction_Rate* respectively.

Most of the cost parameters are typical in supply chain management. The assumptions are all cost parameters associated with the forward supply chain are constant over time and the related costs are proportional to the product flows. But, since the cost modeling in the reverse supply chain is more complicated due to the capacity construction costs, which generally depend on the magnitude of the capacity expansion and are subject to economies of scale. Therefore, this chapter adopts the general cost structure for capacity acquisition by Nahmias (2001) that represents wide variety of industries.

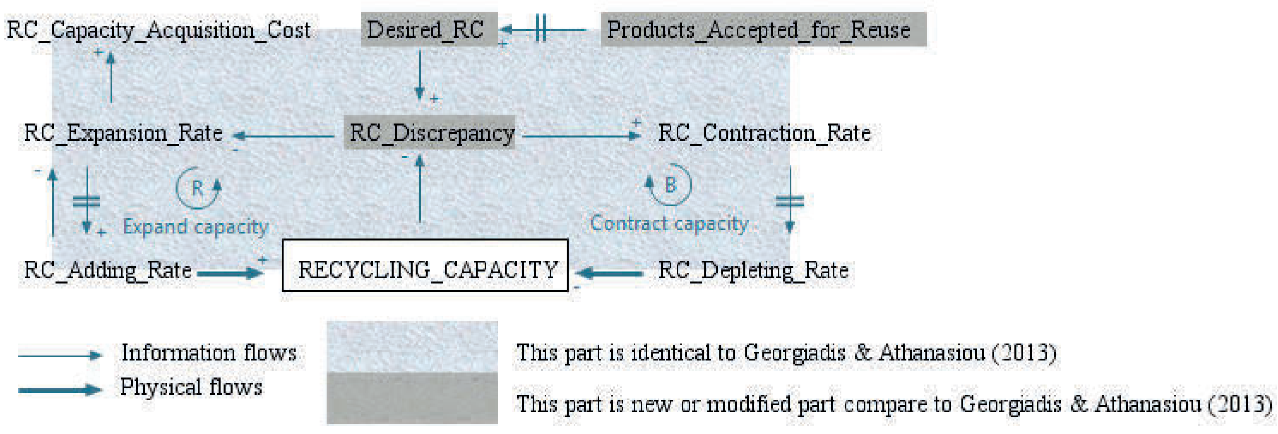

Fig. 5.4 Causal loop diagram of the efficient, flexible recycling capacity planning policy control mechanism

The efficient flexible capacity planning developed here has a close similarity to the capacity planning of (Georgiadis, 2013). Both of them adopted a periodic review for the capacity planning mechanism that considers capacity expansion and contraction policies.

However, there are three major fundamental differences between the concept of capacity planning that is developed here and that developed by Georgiadis (2013). First, his capacity planning is focused on a balanced trade-off between profit and capacity utilization. In contrast, the present paper focuses on a balanced trade-off between sustainability dimensions performance and the existence of a social responsibility fund to support the entire reverse channel. This difference means that the capacity planning here has to solve a much more complex task. Second, his structure of a capacity planning model adopts a self-discarding rate of capacity due to its capacity average lifetime. In contracts, here, such a structure is not adopted. Here, the capacity planning has a balance loop for capacity contraction that is driven by the desired capacity discrepancy. This second difference refers us to the last key difference, which is the product lifecycle. His model did not adopt the nature of the product lifecycle pattern disruption in his capacity planning. In contrast, here, the capacity planning considers this disruption. So in simplified, these keys different are highlighted the capacity planning described in this paper is different to his model, even if they seem to be very similar.

In brief, the mechanism in **Fig. 5.4** is comparable to that of Georgiadis and Athanasiou (2013). However, unlike their mechanism, the proposed model is limited by the social responsibility levels (*SR_Level*) contained in *Desired_RC*, see **Eq. (5.5)**. On the other hand, the period of review is defined by using the decision variable *Pr* in *RC_Discrepancy* for both expansion and contraction, see **Eq. (5.6)**.

$$\mathrm{Desired\_RC}(t) = \begin{cases} 0, & \mathrm{SR\_Level} > 0 \\ \mathrm{delay}_1(\mathrm{Products\_Accepted\_for\_Reuse}(t), \mathrm{a\_RC}, \mathrm{Products\_Accepted\_for\_Reuse}), & \mathrm{Otherwise} \end{cases} \tag{5.5}$$

$$\mathrm{RC\_Discrepancy}(t) = \begin{cases} \mathrm{Desired\_RC}(t) - \mathrm{RECYCLING\_CAPACITY}(t), & t = n \times \mathrm{Pr}\ \mathit{where}\ n = 1, 2, 3, \ldots \\ 0, & \mathrm{Otherwise} \end{cases} \tag{5.6}$$

The characteristic value of K_{r_1} and K_{r_2} in the proposed model is similar to Georgiadis and Athanasiou (2013). In contrast, in the characteristic value of Pr is similar to Vlachos et al. (2007). However, new capacity expansion may be decided only when: (a) the magnitude of discrepancy is above a threshold value *lb* (*lb* = 5% of peak demand (*Peak_Demand*)) expressing the undesirability of frequent small changes; (b) the magnitude of expansion, based on the previous related decision, becomes fully operational, for example *RC_Adding_Rate* = 0; and (c) the fund for expansion is sufficient.

A similar modeling approach is applied to the *COLLECTION_CAPACITY*. The only difference is that the desired level arises as a first-order exponential smoothing of used products (*Used_Products*), unlike in Georgiadis and Athanasiou (2013), whose used products come from the sales of the previous product since they are considering multiple products.

5.4 Experimental design

The experimental design is divided into two parts: first the validation of the SD model and second the running of the experiment by using the validated SD model with its statistical analysis.

5.4.1 System dynamics model validation

The experiment is designed as shown in **Fig. 5.5**. The two key methods in this figure, namely SD and Taguchi design, have a close similarity to the previous research (Low & Chen, 2012). The aim is to analyze the impact of capacity planning on product lifecycle for performance on sustainability dimensions in RLSR by using an SD approach. The first step of the experimental design is to validate the model. The question is: Does the model already have the right internal relationship and behavior or not? In this step, before the model is validated, the basic scenario is defined with the array settings shown in **Appendix A**, with 300 weeks as the simulation period. The simulation is designed with the week as the unit for the period and the euro as the unit of currency. Data from previous related simulation research are used (Georgiadis & Athanasiou, 2013; Georgiadis et al., 2006), but other data for the novel features with their supporting entities are hypothetically generated. Here, Anylogic is used as the simulation software and SPSS is used as the results analysis software.

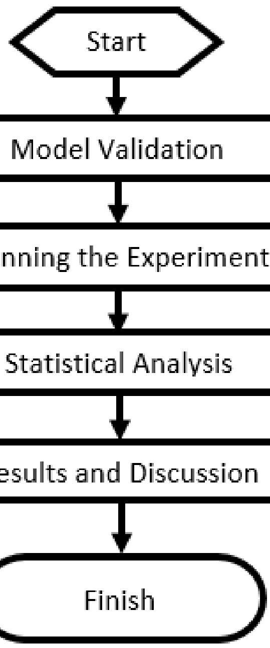

Fig. 5.5 Simulation experiment flow diagram

Hereafter, the model is validated by using a dimensional consistency test, extreme-condition test, and behavior-pattern test in sequence to confirm its validation and build confidence in the model (Forrester & Senge, 1979; Sterman, 2002). Then, after the model validation is confirmed, the second step is conducted. The second step is running the experiment, which will be discussed in Section 4.2. Finally, the results and discussion will be presented in Section 5.

The results of the proposed SD model validation are described in three steps. First, in the Anylogic software test, no dimensional inconsistency or error was found. Second, it was possible to continue to the next step, namely the extreme-condition test. In this step, all level-type entities' initial inventories are set as 0 with no legislation (*Legislation*) and no raw materials (*Initial_Non_Renewable_Materials* is set as

0). Then after the simulation, the result shows that there is no procurement (*Procurement* = 0), no production (*Production* = 0), no shipment from the manufacturer to the distributor (*Shipment* = 0), no delivery to the customer (*Delivery* = 0), or no sales (*Sales* = 0) with no reverse logistics activity (*COLLECTION_CAPACITY* = *RECYCLING_CAPACITY* = 0). Then, the measured performance dimensions produce zero-value performances (*Total_Supply_Chain_Profit* = *GI* = *Social_Performance* = 0). The last is a behavior-pattern test; in this case the *SR_Level* is set to 0.2 and then the simulation is run. The behavior of two variables is checked against the behavior shown by previous research. The results of the simulation are that the collection percentage (*Collection_Percentage*) and the recycling percentage (*Recycling_Percentage*) are in agreement with the results of Georgiadis and Besiou (2008).

5.4.2 Running of the experiment and statistical analysis

The experiment and statistical analysis are based on the Taguchi experiment design (Antony, 2003; Ramachandran & Tsokos, 2015). The aim of this step is to find the statistical significance value with its power of the impact of capacity planning on product lifecycle for performance on sustainability dimensions. This method draws on the earlier research conducted by Georgiadis et al. (2006) regarding finding the significant effect on the performance by using Analysis of Variance (ANOVA). Then it is extended using the method from Georgiadis and Athanasiou (2010) to find the relationship's power of significance by using Partial Eta-Squared (PES).

Table 5.2 shows the control factors (inner array) with their set of levels. It consists of the policy parameters in our model, such as $\text{SR\_Level}, K_{C_1}, K_{C_2}, K_{r_1}, K_{r_2}, Pc, \text{and } Pr$. The value of each level in **Table 5.2** is generated by the following steps. First, the SR_Level is set based on the value given in Chapter, with the lowest value as the initial value of the lower bound or (–) value. Second, the values of the rest of the policy parameters are set. The lowest values given in Vlachos et al. (2007) and Georgiadis and Athanasiou (2013) are set as the initial values for their (–) values. Third, the values are tested in the preliminary simulation. Last, on a sequential basis, the values are then changed (expanded) heuristically to find the range of solutions for the combination of set values of policy parameters given in **Table 5.2**. Once a parameter has been changed, the others are set to remain constant. In contrast with Georgiadis et al. (2006) and Georgiadis and Athanasiou (2010), the values given in **Table 5.2** are not the optimal set values. The values are set within the range of policy parameter settings that could deliver the two most critical conditions. First, the *SR_Fund* should always be available to finance reverse logistics activities. Second, due to the complexity of our performance dimensions, the values given in **Table 5.2** should have enough capability to show a wide impact on all dimensions of performance. So, in the end, they can be representative of a broad range of policy parameter settings that could show their wide impact on performances in RLSR.

So the set of levels for control factors in **Table 5.2** is no longer typical for the recycling industry. Even though the values in **Table 5.2** are initiated based on the previous papers (Georgiadis & Athanasiou, 2013; Vlachos et al., 2007), but the values have been modified through several steps to meet the research needs of this study. In addition, the contrast to the values generated by the previous papers (Georgiadis & Athanasiou, 2010; Georgiadis et al., 2006) has been discussed in the previous paragraph. So now the values of **Table 5.2** are not general for the recycling industry, but are specific values that meet the research needs of the study, even though the initial values themselves are typical for the recycling industry.

On the other hand, **Table 5.3** shows the noise factors (outer array) with their set of levels. It consists of uncertainty parameters that are considered in our SD model, such as L, P, and RI. Here, the Residence Index is defined as in Georgiadis and Athanasiou (2010) as the mean time for which the product is owned by the consumer divided by the length of one product lifecycle. The value of each level in **Table 5.3** is equal to that given from their parameter settings and Georgiadis et al. (2006), including the product lifecycle patterns used in this numerical simulation as shown in **Fig. 5.6**. So **Table 5.3** can be representative of a broad range of both product lifecycle types and recyclable products.

That is why all these typical values for the recycling industry in **Table 5.3** are still adopted since these values represent the characteristics of the recycling industry in general. So it means these values could represent the recycling industry with social responsibility aspects, like the study in this chapter.

Table 5.2 Control factors (inner array) and set of levels

Control factors	(−)	(+)
SR_Level	0.2	0.3
K_{C_1}	1.5	3
K_{C_2}	1	1.5
K_{r_1}	1.4	2.6
K_{r_2}	1	1.2
Pc	10	40
Pr	10	40

Table 5.3 Noise factors (outer array) and set of levels

Outer factors	Set of levels		
Lifecycle (weeks)	250 (medium)		500 (long)
Pattern (length of the maturity stage)	Pattern 1[a]	Pattern 2[b]	Pattern 3[c]
Residence Index (RI) [d]	0.2 (low)	0.35 (medium)	0.5 (high)

[a] Maturity stage length equal to: 3/5 of lifecycle
[b] Maturity stage length equal to: 1/3 of lifecycle
[c] Maturity stage length equal to: 1/5 of lifecycle
[d] Residence Index $= \frac{\mu_{Resident\ Time}}{Lifecycle}$

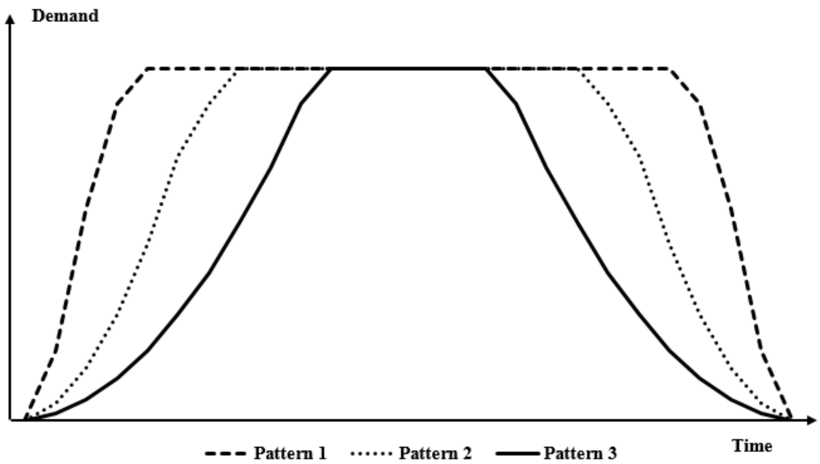

Fig. 5.6 Product lifecycle patterns used in the numerical simulation

Remanufacturing is a specific type of recycling (Bernard, 2011). In addition, the research in this paper focuses on social responsibility issues in CLSCs either with recycling network or remanufacturing (a specific type of recycling) network like Nikolaou et al. (2013). Therefore, some of the product families as stated in Georgiadis et al. (2006) and Georgiadis and Athanasiou (2010) could be the representative for the needs of this paper. In addition, a real world example of the proposed model as stated in **Section 5.1** belongs to the stated product families in both research groups.

Then, since the number of all possible combinations of these seven decision variables shown in **Table 5.2**, $2^7 = 128$, is prohibitively large, the examination only includes the subset of eight combinations that correspond to the 2^{7-4} fractional factorial design shown in **Table 5.4**. In view of that, following the approach and adopting the terminology of Taguchi's parameter design, the numerical experiment is set up as a product array experiment, where two separate experimental designs (arrays) are used and observations are recorded for all combinations of the two designs. The inner array (control array) is a 2^{7-4} fractional factorial design with eight combinations. On the other hand, the outer array is a full factorial design with $2 \times 3^2 = 18$ combinations. The outer array is shown in **Table 5.5**. So, the total number of experimental runs is $18 \times 8 = 144$. Each of the eight combinations of the inner array provides 18 combinations of observations of the outer array. Therefore, it allows the use of ANOVA to determine which control factors could significantly affect the noise factors and their interactions for the measured dimensions performance. Here, the significant level of ANOVA is set as 0.01 ($\alpha = 1\%$). The expected findings of the experiment are to show which policy parameters (control factors) have a significant effect on countering the effect of uncertainty (noise factors) for the measured performances. At the end of the test, the *p*-value is examined, with two possible interpretations:

- *p*-value $\leq \alpha$: Policy parameters have a significant effect on noise factors for the measured performances.
- *p*-value $> \alpha$: Policy parameters do not have a significant effect on noise factors for the measured performances.

In addition, the Partial Eta-Squared (PES) is also examined. PES shows, in general, the magnitude of the effect of each control factor on the noise factors (always between 0 and 1). Here, the power of significance of PES is classified into the following categories according to Georgiadis and Athanasiou (2010):

- PES > 0.7 : strong
- $0.7 \leq$ PES < 0.5 : medium
- PES ≤ 0.5 : weak

All 144 experimental runs were studied over the time horizon of the lifecycle. All arrays in the system dynamics model to support this experimental design are set equal to the value shown in **Appendix A**. The data of experimental runs are analyzed by using SPSS software. The results are shown in **Table 5.6**. The discussion of the results will be focused on the benefits and disadvantages of the SD model features, and then the results of numerical experiments will be benchmarked with the previous research findings of Georgiadis et al. (2006) and Georgiadis and Athanasiou (2010). Here the second research group is added as the benchmark results in this paper since they are the extension of research that conducted in the first research group for analyzing the impact of behavior in RL due to product lifecycle with inherited uncertainty. They add more product lifecycle parameters and consider multi-products. So the major fundamental differences between our models and both research groups are the social responsibility elements (including the capacity planning policy) with its interrelated sustainability dimensions and the product lifecycle with its inherited uncertainties. Here Georgiadis and Athanasiou (2013) and in Chapter 3 are not used as the comparative studies since both research groups not focus on the impact of behavior. So their results are not comparable to the results in this chapter.

Table 5.4 The 2^{7-4} experimental design for the inner array

Control factors	1	2	3	4	5	6	7	8
SR_Level	−	+	−	+	−	+	−	+
K_{C_1}	−	−	+	+	−	−	+	+
K_{C_2}	−	−	+	+	+	+	−	−
K_{r_1}	−	−	−	−	+	+	+	+
K_{r_2}	−	+	+	−	+	−	−	+
Pc	−	+	−	+	+	−	+	−
Pr	−	+	+	−	−	+	+	−

Table 5.5 The 2×3^2 experimental design for the outer array

Case	Lifecycle	Patterns	Residence Index
1	250	1	0.2
2	250	2	0.2
3	250	3	0.2
4	500	1	0.2
5	500	2	0.2
6	500	3	0.2
7	250	1	0.35
8	250	2	0.35
9	250	3	0.35
10	500	1	0.35
11	500	2	0.35
12	500	3	0.35
13	250	1	0.5
14	250	2	0.5
15	250	3	0.5
16	500	1	0.5
17	500	2	0.5
18	500	3	0.5

5.5 Results and discussion

This section consists of two sub-sections. First, the results of numerical simulation are described and the findings are discussed. Second, this chapter's social responsibility concept is discussed along with its numerical simulation findings.

5.5.1 The results and findings of the numerical simulation

The results of statistical analysis of the experimental run are shown in **Table 5.6**. Examination of the results shown in **Table 5.6** leads to the four observations below regarding policy parameters as control factors (SR_Level, K_{C_1}, K_{C_2}, K_{r_1}, K_{r_2}, Pc, and Pr) in RLSR for sustainability with the considered uncertainty parameters as noise factors (L, P, and RI).

First, the policy parameters have an effect on any measured performances and uncertainty conditions, except for Pc in the L * RI condition for social performance and all policy parameters in both P * RI and L * P * RI conditions for both environmental and social performances. This is attributed to the fact that the SD model has a more direct implication for economic performance than for environment and social performances. Since the driving force for collection capacity decisions is the number of products used (*Used_Products*), the system will only be expanded when the review period is achieved. Both combinations deliver the consequence that there is much more slack time for recycling capacity expansion.

Second, the economic dimension performance is strongly affected by policy parameters in most of the uncertainty conditions. There are only two exceptions to this point, namely the condition where there is an interaction of P * RI and the condition where there is a complex interaction of L * P * RI. In these two conditions, the policy parameters could only affect the economic performance in the medium term. As a matter of fact, the economic performance is a result of direct influence. In addition, more delay occurs for both *Demand* and *Used_Products* because of the interaction of control factors such as P * RI and L * P * RI. Therefore, this more delay causes more slack time for *Sales* of new products to come into *Used_Products* and more rarely capacity expansion. So, *Demand* and *Used_Products* become more prevalent during the time period of the simulation.

Third, the performance on the environmental dimension is affected by the policy parameters with various effects and powers of significance. First, in conditions where only L exists, their effect is strong. Second, in conditions where only P or RI exists, their effect is medium-sized. Third, in conditions where other interacting uncertainties exists, such as L * P and L * RI, their effect is weak. Lastly, in conditions where the other interacting conditions exist, such as P * RI and L * P * RI, no effect can be achieved by the policy parameters. Unfortunately, the environmental performance results from the indirect effect of the policy. Moreover, the environmental performance depends on the intersection between two interests. First, it is necessary to respond to *Used_Products* as soon as possible by expanding both the collection and recycling capacity. However, this necessity is strongly limited by the time of expansion (review period), economies of scale for the expansion, and the availability of the social responsibility fund. Second, the first moves of capacity expansion is driven after *Sales* becomes *Used_Products*. Therefore, the environmental performance is received two slack periods before the green image could start to increase: the time between backlog demand (*Demand_Backlog*) and *Sales* and the time between *Sales* products and *Used_Products*. In the end, both interests cause the policy parameters to have less effect on countering the uncertainty.

Fourth, the performance on the social dimension is the performance that is hardest to influence in this model. First, no strong effect can be achieved by the policy parameters. Second, the medium effect only exists in the condition with L. Third, under the other conditions, such as the conditions with P, RI, L * P, and L * RI, their effect is medium-sized, except for Pc, which has no effect under the condition of L * RI. Finally, under the P * RI and L * P * RI conditions, no effect could be delivered by the policy parameters. Unfortunately, the social performance results from both economic and environmental performances. This condition has a high cost. If there is a disturbance or if more slack time occurs for any reason in the economic and environmental performances, there will be a direct effect on the social performance. This situation means that the social performance is the type of performance that is hardest to influence with the policy parameters. Moreover, it also becomes the type of performance that is most vulnerable to the effects of uncertainty.

Then, before moving on to the comparative study of the results shown in **Table 5.6**, the fundamental differences between my models and the previous ones (Georgiadis et al. (2006) and Georgiadis and Athanasiou (2010)) need to be discussed. Accordingly, there are five fundamental differences discussed. First, unlike both research groups, this chapter focuses on more complex dimensions of performance. Second, in contrast to both research groups, here the consideration of *SR_Fund* availability to support the RL activity is a must. Third, unlike the first research group, here the examination of the impact of behavior is designed to measure the power of significance of the policy parameters. Fourth, unlike the proposed model, the second research group provides more insight in terms of wider uncertainties that are considered, such as peak demand, failure rate, and entry time. Fifth, differ with both research groups, Pc and Pr are considered in the model as the review period of capacity planning to earn more savings from economies of scale for capacity expansion.

In contrast to the five fundamental differences mentioned above, the comparative study is limited to the key different and similar findings from Georgiadis et al. (2006) and Georgiadis and Athanasiou (2010) by focusing on economic performance and temporarily omits (but still considers) levels of contribution to social responsibility and the review period in policy parameters. **Table 5.6** shows a comparison of the results of this chapter versus previous research results, revealing the two following features of RLSR, which are discussed below.

First, the findings of this chapter agree with those of Georgiadis and Athanasiou (2010) in showing that each parameter in capacity planning has an effect on the model's economic performance. Even though they consider a wider selection of uncertainties along with their interactions, some of their results are comparable to those of this chapter. However, this chapter's claims about the power of significance levels are different. First, in the condition where L exists as an uncertainty, they found that the power of significance is weak, but here it is found that the power of significance is strong. Second, in the condition with P, they found that K_{r_1} has a weak effect, while K_{C_1} and K_{r_2} have a medium effect and K_{C_2} has a strong effect. But here, all policy parameters have a strong effect. Third, in the condition with RI, they found that only K_{r_1} has a strong effect, but the others have a weak effect. In contrast, this study found that all policy parameters still have a strong effect. Last, their findings for all other uncertainty conditions show that the effect is weak, but this chapter shows that the effect is still strong for the conditions with L * P and L * RI. For the rest of the conditions, the effect occurs in the medium term.

Second, in contrast, most this chapter's findings are in contradiction with those of Georgiadis et al. (2006). This is because their outer array focuses on cost and time, while the model under study here uses uncertainty parameters as the outer array. Even though they are proposing an optimal capacity planning policy under settings of the outer and inner arrays, their results have a greater effect on the economic performance, unlike the results of this chapter, which have a wider dimensions performance. This study finds that policy parameters have a significant effect in each condition, which differs from their findings. First, they only agree that K_{C_2} and K_{r_1} have a significant effect under the condition in which L exists. But the other policy parameters have a non-significant effect. Second, they do not agree with this chapter's findings in the condition where P exists as uncertainty. They claim that K_{r_1} has a non-significant effect. Third, they agree that K_{C_1} is the only policy parameter that has a significant effect under the condition in which RI exists. Fourth, they agree that K_{C_2} is the only policy parameter that has a significant effect under the condition in which L * P exists. Last, in the rest of the conditions, the policy parameters have a non-significant effect.

In brief, the comparison of similar findings for this chapter to Georgiadis et al. (2006) and Georgiadis and Athanasiou (2010) by focusing on $K_{C_1}, K_{C_2}, K_{r_1},$ and K_{r_2} as the policy parameters, economic dimension as the performance measurement, and no PES value examination, they agree for three major similar findings. First, for K_{c_1} has a significant effect under the condiction of P and RI. Second, for K_{c_2} has a significant effect under the condition of P. Third, for K_{r_2} has a significant effect under the condition of L and P. Thus, these findings deliver two sound managerial insights. First, $K_{C_1}, K_{C_2},$ and K_{r_2} are the most significant policy parameters to improve economic dimension of sustainability in CLSCs while it tackles the product lifecycle with its inherited uncertainty. Second, P is the only noise parameter that could be tackled significantly instead of others. So in simplified both findings agree that at least by focusing on collection facility (K_{C_1}, K_{C_2}), the managers could minimize the impact of product lifecycle (P) in forward channel for economic dimension of sustainability in CLSCs.

Table 5.6 The effects of control factors on noise factors for the sustainability dimensions performance

Sustainability dimensions	L	P	RI	L * P	L * RI	P * RI	L * P * RI
Economic dimension							
SR_Level	+++	+++	+++	+++	+++	++	++
K_{C_1}	+++	+++	+++	+++	+++	++	++
K_{C_2}	+++	+++	+++	+++	+++	++	++
K_{r_1}	+++	+++	+++	+++	+++	++	++
K_{r_2}	+++	+++	+++	+++	+++	++	++
Pc	+++	+++	+++	+++	+++	++	++
Pr	+++	+++	+++	+++	+++	++	++
Environmental dimension							
SR_Level	+++	++	++	+	+	0	0
K_{C_1}	+++	++	++	+	+	0	0
K_{C_2}	+++	++	++	+	+	0	0
K_{r_1}	+++	++	++	+	+	0	0
K_{r_2}	+++	++	++	+	+	0	0
Pc	+++	++	++	+	+	0	0
Pr	+++	++	++	+	+	0	0
Social dimension							
SR_Level	++	+	+	+	+	0	0
K_{C_1}	++	+	+	+	+	0	0
K_{C_2}	++	+	+	+	+	0	0
K_{r_1}	++	+	+	+	+	0	0
K_{r_2}	++	+	+	+	+	0	0
Pc	++	+	+	+	0	0	0
Pr	++	+	+	+	+	0	0

Abbreviations: L = Lifecycle; P = Pattern; RI = Residence Index
Legend:
0 = This control factor has 'no effect' on this particular noise factor(s).
\+ = This control factor has 'a significant effect with a weak power of significance' on this particular noise factor(s).
++ = This control factor has 'a significant effect with a medium power of significance' on this particular noise factor(s).
+++ = This control factor has 'a significant effect with a strong power of significance' on this particular noise factor(s).

5.5.2 The proposed social responsibility concept and the findings of numerical simulation

The concept of social responsibility in this chapter is aligned with "the company as the real entity theory" for sustainability (Lozano et al., 2014). As a real entity, the company has rights and responsibilities. The company has the right to produce and transport the product. But on the other hand, the company has a responsibility to overcome the impact on both the environment and society due to their rights activities. This mutualism between rights and responsibilities is applied not only to the company but also to the consumer (Caruana & Chatzidakis, 2013). The consumer has the right to consume the product, but the consumer has a responsibility for overcoming the impact on both environment and society due to his/her consumption activity; for example, the consumer is responsible for his/her used products. Then, put simply, on the companies' side, the social responsibility acts are called Corporate Social Responsibility (CSR). On the other hand, on the consumers' side, their social responsibility acts are called Consumer Social Responsibility (CnSR). That is another reason why RLSR is chosen in this paper, since RLSR could integrate CSR as the companies' social responsibility and CnSR as the consumers' social responsibility.

This concept of social responsibility has a close relationship with ISO 26000. There are seven core subjects in ISO 26000 (ISO, 2015). This chapter's concept is related with four out of seven of these core subjects. First, the concept is related to core subject of 'organization'. The involvement of most actors in the supply chain including the consumer is the key reason for conducting RLSR, as stated in the Introduction.

Second, the concept is related to core subject of 'environment'. The key activity in this chapter is reverse logistics, which is reusing used products to conserve the environment by minimizing the amount of products disposed of. Third, the concept is related to core subject of 'fair operating practice'. Here both company and consumer are balancing their rights and responsibilities as real entities as stated in the previous paragraph. Last, the concept is related to core subject of 'consumer issues'. Here the consumer is carrying out his or her social responsibility (CnSR) by paying the premium price to support recycling activity and returning the used products to the collection facility. So there is consumer involvement here.

Even though the concept of social responsibility in this chapter has a close relationship with ISO 26000, ISO 26000 is not considered here. This is because the social responsibility should adopt the uniqueness of local value where the company operates. So due to this local value adoption, ISO 26000 is not verifiable by a third-party certification, unlike ISO 9000 or ISO 14000 (Castka & Balzarova, 2008a, 2008b). This is why ISO 26000 is becoming a guideline for social responsibility rather than a quality standard of social responsibility (ISO, 2015).

In contrast, by looking at the company and consumer in the supply chain as the organism entities, no unique local value should be discussed in social responsibility. Now the focus of social responsibility should be only on the "mutualism", which represents the balance between the rights and the responsibilities of both company and consumer in the supply chain. Therefore, a sustainable supply chain could be achieved through social responsibility by maintaining this mutualism and focusing on sustainability dimensions' performance such as the economic, environmental, and social performances. Now this relationship — the "mutualism" and sustainability dimensions —and the reason why ISO 26000 is not considered here — just as guidance — are clearly shown.

In addition, here the driving forces for why the companies are carrying out social responsibility are adopted in the SD model. The driving forces that are adopted in the SD model consist of regulations, economic instruments, and self-interest incentives (e.g. cost savings). That is why the model considers two features. First, *Legislation* and *Penalty* are adopted for regulation driving force of social responsibility. Second, the model is measuring the economic return from social responsibility activities, as the social performance measurement for the driving force from the economic instrument and self-interest incentives viewpoint of social responsibility.

So the findings of this study combined with the proposed social responsibility concept, methods, and SD model features reveal six interesting academic insights. First, RLSR is one appropriate way of looking at companies and consumers as the real organism entities in carrying out social responsibility. Second, the social responsibility concept in this chapter aligns with four out of seven core subjects in ISO 26000 as the global guideline for social responsibility. Third, the findings in this chapter support the theory about corporate sustainability from the perspective of the theory of the company as the real entity. Fourth, the interrelated sustainability dimensions could provide one possible answer to show how social responsibility could achieve corporate sustainability. Fifth, the findings in this chapter could help policy makers to maintain their RLSR sustainability dimensions' performance as explained in Sub-section 5.1. Last, the system dynamics work well to support the needs of the methods in delivering a complex quantitative relationship entities model in this study.

5.6 Summary

This chapter's findings contribute to the relatively limited academic knowledge on the examination of the impact of behavior in reverse logistics as the social responsibility because of two main features. First, the efficient flexible capacity planning is established as the policy parameters. Second, some high-impact performance product lifecycle with its inherited uncertainties, such as lifecycle (L), patterns (P), and residence index

(RI), are considered. Here, the numerical experiment is set up under fixed cost and time parameter settings. The findings show that the proposed policy parameters can tackle the uncertainties to enhance the measured performance on a certain level of significance. However, there are a few exceptions to that. The policy parameters for the environmental and social performances have a non-significant effect under the conditions with P * RI and L * P * RI. Therefore, the policy parameters could only accomplish the optimal measured performance dimensions under all conditions with uncertainties, except under the P * RI and L * P * RI conditions.

The present chapter is also relevant for managers or policy makers who are carrying out RLSR. The findings in this chapter will give them a better understanding of the relationship between capacity planning, product lifecycle with its inherited uncertainties, and sustainability performance. In the end, this better understanding will improve policies in capacity planning to tackle product lifecycle with its inherited uncertainties for sustainable RLSR.

Although the uncertainties considered here cannot be regarded as exhaustive, they give an insight into the field of social responsibility in the supply chain, allowing managers to tackle some uncertainties in their supply chains to gain better performances. Moreover, the chapter provides additional evidence for strategic policy makers in firms that integrating social responsibility in the supply chain can achieve sustainability. Finally, a possible extension could be the study of the other uncertainties, disaster occurrence.

In Chapter 4, the effect of the noise level on the performance measures are analyzed similar in this chapter. However, the performance mays also be affected by the level of demand uncertainty. Therefore, this chapter focuses on the demand uncertainty and the performance analysis of RLSR systems. In addition, Chapter 4 capacity planning policy is the basis work for the capacity planning policy in this chapter.

Chapter 6 Conclusions and Future Works

6.1 Conclusions

A simplified SD model of RLSR to show how CSR produces economic, environment and social returns through RLSR, is constructed. The model considers the trade-off between market response and environmental performance through premium price. The numerical experiment, it's found that CSR could produce both TBL performance enhancement and digressions.

This thesis contributes to the relatively limited but important academic knowledge on the study of social responsibility issues in CLSCs in order to achieve optimal sustainability dimensions' performance in the interrelated triple bottom line framework. This contribution is delivered under fixed cost and time parameter settings.

Three main findings are emerged. They are:

- The model greatly contributes on how CSR could emerge not only economic, but also environment and social returns through RLSR to reduce CSR' trivial risk and achieving sustainability.
- It is found that the optimal sustainability dimensions performance can be delivered by the efficient flexible capacity planning while tackling the uncertainties. However, the proposed capacity planning has some limitations. This capacity planning can produce a smaller loss of sustainability dimensions performance while making a smaller sacrifice in terms of adaptability to counter the effect of the product lifecycle with its inherited uncertainty. However, policy makers need to decide on their preferred order of priority of the sustainability dimensions.
- It's found that the relatively limited academic knowledge on the examination of the impact of behavior in reverse logistics as the social responsibility because of two main features. First, the efficient flexible capacity planning is established as the policy parameters. Second, some high-impact performance product lifecycle with its inherited uncertainties, such as lifecycle (L), patterns (P), and residence index (RI), are considered. Here, the numerical experiment is set up under fixed cost and time parameter settings. The findings show that the proposed policy parameters can tackle the uncertainties to enhance the measured performance on a certain level of significance. However, there are a few exceptions to that. The policy parameters for the environmental and social performances have a non-significant effect under the conditions with P * RI and L * P * RI. Therefore, the policy parameters could only accomplish the optimal measured performance dimensions under all conditions with uncertainties, except under the P * RI and L * P * RI conditions.

The present thesis is also relevant for managers or policy makers. While the uncertainties considered here (**Chapter** 4 and **5**) cannot be regarded as exhaustive, they offer insights to social-responsibility-related managers to help them tackle some uncertainties in their supply chains with RLSR to achieve better performances. Moreover, the thesis offers strategic policy makers in firm additional evidence that integrating social responsibility in the supply chain can lead to the achievement of sustainability.

6.2 Future Works

The SD model constructed under this study is made theoretically. Although the real world application of social responsibility concept in this study is exists, but this theoretical model will have small representation. So there are two possible extensions of the research. First, it could be the study of the other uncertainties, such as the level of used products. Second, the future works should give priority to (1) find the others way to integrate CSR in supply chain, other than through RLSR, and (2) proposes an empirical research to support the findings of each chapter in this thesis.

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Appendix A

Array settings in basic scenario for SD simulation of each chapter

Legislation (L) | Standards set by legislators | 1: Collection_Percentage; 2: Recycling_Percentage; 3: Limit_of_Recyclability | L = {0.8, 0.75, 0}

Legislators' Behavior (LB) | Social sensitivity behavior of legislators | 1: Low; 2: Medium; 3: Normal; 4: High | LB = {0, 0, 0, 1}

Market Composition (MC) | Customer social sensitivity fraction in the market | 1: Low; 2: Medium; 3: Normal; 4: High | MC = {0, 0, 0, 1}

Market Behavior (MB): Social sensitivity behavior of market | 1: Low; 2: Medium; 3: Normal; 4: High | MB = {0, 0, 0, 1}

Raw Materials (R) | Number of specific types of raw materials | 1: Non-recycled; 2: Recycled | R = {0, 0}

Author's Publication

The author's publications related to this thesis consist of international journal papers and international conference papers. The published international journal papers are shown in **Table A**. The published international conference papers are shown in **Table B**.

Table A Published international journal papers

Code	Paper's information
1-A	**Sudarto, S.**, Takahashi, K., Morikawa, K. **2014**. **Closed loop supply chain model with corporate social responsibility**. *Asia-Pac. J. Ind. Manag. V*(1), 30–38.
1-B	Sudarto, S., Takahashi, K., & Morikawa, K. (2016). The impact of capacity planning on product lifecycle for performance on sustainability dimensions in Reverse Logistics Social Responsibility. *Journal of Cleaner Production*, *133*, 28–42. http://doi.org/10.1016/j.jclepro.2016.05.095

Table B Published international conference papers

Code	Paper's information
2-A	**Sudarto, S.**, Takahashi, K., Morikawa, K. **Designing a conceptual model of integration between corporate social responsibility and supply chain in relationship to sustainable indicators**, Proceeding of the 17th International Conference on Industrial Engineering Theory, Applications and Practice (IJIE2013), October 6-9, Busan, Korea, **2013**, pp. 377-386.
2-B	**Sudarto, S.**, Takahashi, K., Morikawa, K. **Closed loop supply chain model with recycling activity of corporate social responsibility**. Proceedings of the 12th International Conference of Industrial Management (ICIM2014), September 3-5, Chengdu, China, **2014**.
2-C	**Sudarto, S.**, Takahashi, K., Morikawa, K. **Efficient flexible long-term capacity planning for optimal sustainable dimensions of reverse logistics social responsibility: a system dynamics approach**. Proceedings of the 23th International Conference on Production Research (ICPR2015), August 2-5, Manila, Philippine, **2015**.