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Research article

A bi-objective decision support tool based on system dynamics and discrete event modelling for sustainable supply chain

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Abstract

Based on the development trend of sustainable concepts and the implement ability of composites combined with Agave Bagasse Fibre (ABF) and Polyethylene Terephthalate (PET). The purpose of this paper is to design a bi-objective decision support tool for supply chain of composite material which combined with ABF and PET. Through the production, processing, recycling, and reprocessing of composite materials, the sustainable supply chain model of four different schemes is designed, and the data results of each scheme model are calculated and analysed. The tool can support supply chain modelling solutions that seek best practices for sustainable supply chains and optimize resource efficiency through cost and carbon dioxide emissions. The sustainable supply chain model was designed, created, and optimized in AnyLogic software using System Dynamics and Discrete Event Simulation modelling methods based on the supply chain model established by previous researchers. According to the analysis results of the model data, the reasonable design of the whole process can effectively reduce the cost and carbon dioxide emissions and achieve the effectiveness and implementation of the sustainable supply chain. The results of this study will provide reference for more sustainable supply chain models in the future. Further research on composite materials can be carried out by combining with practice.

Keywords: Sustainable agricultural waste; Sustainable supply chain; System dynamics; Discrete event simulation, Design Thinking

1. INTRODUCTION

A recent report released by the UK government on December 31, 2020, shows that Mexico has become one of the UK's most important trading partners, with total trade revenue amounting to a business worth approximately £5.3 billion, making it a key trading partner for the United Kingdom (UK) in the face of Brexit. Imports from Mexico amount to around £2.7 billion per year. Spirits like Tequila, Mezcal, Sotol, and Charanda are the top five sources of imports overall (GOV.UK, 2020). Tequila is derived from the agave plant, which is steamed at high temperature and then obtained by grinding to obtain the juice. During the grinding process, agave plants will produce a woody fibre called agave bagasse residue, but because the annual production of agave bagasse fibre exceeds about 300,000 tons, the environmental problems associated with the treatment of sugarcane residue have always existed, such as landfill disposal (CRT, 2021), (Huerta-Cardoso, Durazo-Cardenas, Longhurst, et al., 2020). The bagasse fibres have properties that naturally lend them to other uses, such as upcycling into green products (Huerta-Cardoso, Durazo-Cardenas, Marchante-Rodriguez, et al., 2020). In addition, research on agave residues has been limited to studies of material properties (Huerta-Cardoso, Durazo-Cardenas, Longhurst, et al., 2020), and there is a lack of research on the commercial effectiveness of agave residues. Therefore, through the analysis of the research gaps and future trends, through the reuse of agave residue and

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efficient utilisation applied to the supply chain, the supply chain is sustainable and in line with the circular economy concept (Kusumowardani et al., 2022). This will help to ensure resource efficiency, sustainable production and consumption and reduced negative environmental impacts through effective and strategic recycling in line with the circular economy (Duque-Acevedo et al., 2020).

To date, there has been considerable research and development in to "green" supply chains (Subramanian & Gunasekaran, 2015), including elements for sustainability and carbon emission reduction in products (Papachristos, 2014). The concept of interaction based to economic activity and natural symbiotic cycles can be applied to a sustainable chemical industry (McElroy et al., 2015), providing ideas on how to apply the concepts of low carbon emissions, reuse and symbiosis with nature to preserve resources and achieve sustainability.

Compared to traditional supply chain management practices, sustainable supply chains consider carbon emissions from manufacturing and transportation. On the other hand, the people, products, and manufacturing technologies involved in the clean supply chain are challenging, as they also need to consider the carbon footprint of manufacturing and transportation.

Multi-criteria decision making has been used in many areas such as recycling of medical waste (Liu et al., 2022), forecasting the sustainability of renewable energy for industry 4.0 (Mastrocinque et al., 2022), measuring the performance of resilient sustainable supply chains (Vergara et al., 2023), supplier selection for small manufacturing companies (Rodrigues et al., 2022) etc. The aim is to help decision makers (or customers) to find better solutions by analysing the results from multiple perspectives, thus improving the efficiency and effectiveness of implementation (Önden et al., 2023). But to date, no researcher has analysed the recycling of packaging through the multi-criteria decision model.

So, the aim of this study is to design a decision support tool based on the simulation technique: system dynamics and discrete event simulation to have to find the best scenario for the packaging industry with the recycled sustainable. To design, observe and analyse the effectiveness and implementability of sustainable supply chain design, the design and simulation of the supply chain will be completed through the methods of System dynamics and Discrete Event Simulation.

Due to the complexity of the supply chain itself, each link will interact with other related links (Elgazzar et al., 2012). In addition, uncertain factors will also affect the link settings in the supply chain, such as changing technology and unpredictable market conditions (Mancheri et al., 2019). In this system, manufacturers, suppliers, distributors, retailers, transportation and other information service providers are all essential stakeholders in the supply chain (Chow D, Heaver T, 1999). In addition, the specific goal of the supply chain is to control location, production, inventory, and handling of products. Use data-driven means to analyse the relationship between transportation, costs, and profits to maximise profits (i.e., profits). In addition, recycled used products have become an essential part of the sustainability direction of today's landscape.

In the circulation link of the supply chain, the setting of supply chain inventory is particularly important, the data control of inventory will be an important factor affecting suppliers and users, in addition, the supply chain model lacks the concept of supply chain management (Fritz, 2022), resulting in statistics and calculation of prices, manufacturers' production capacity, etc., which is also the challenge of the supply chain model in the design, improvement and innovation (Feng, 2012).

This work is guided by the double-diamond method of design thinking (Design Council, 2021) to develop a supply chain which will conform to the concepts of green, sustainable and circular economy, to observe and develop the commercial implementation ability of the recycling process for agricultural waste. Four steps of the double-diamond method: discover, define, develop and deliver, were used to help the development of this study (Fig. 1). The session in the study will follow the iterative principle (Design Council, 2021) to help identify possible errors and gaps in the model design, or model design shortcomings, and make timely improvements.

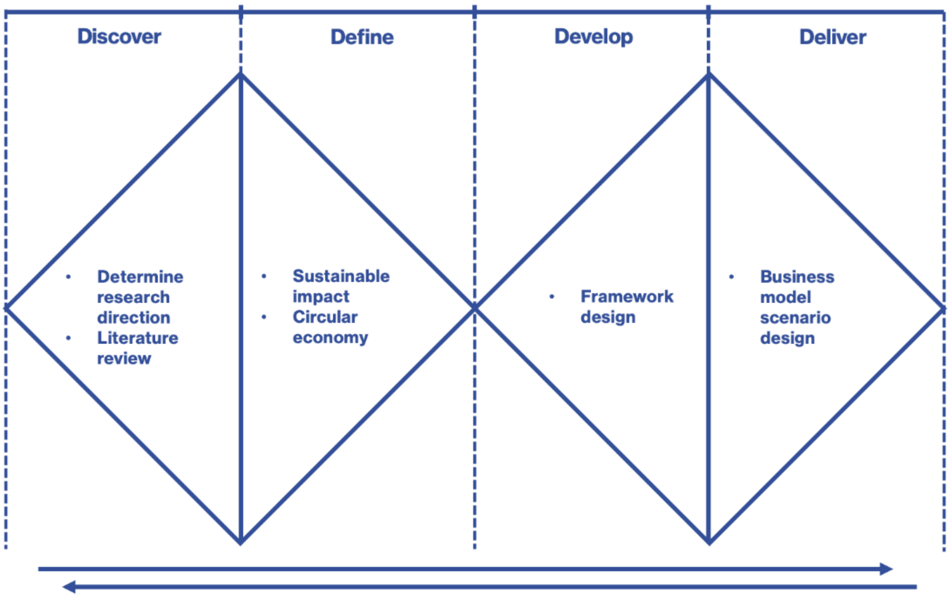


Figure 1. Double-diamond flowchart of the study

Designing, creating, data collection and analysis of this supply chain model by system dynamics and discrete event simulations. Supply chain design is the main goal of this article. The green composite material combined with Agave Bagasse Fibre (ABF) and Polyethylene Terephthalate (PET) is a hypothetical raw material. The processing and production of transport packaging boxes is a hypothetical product. The price of recycling and manufacturing is set to improve the accuracy and reliability of the supply chain design. The sustainable supply chain model for system dynamics and discrete event simulation draws on the previous typical supply chain model as the primary model for development and innovation. In the model's design, the composite material combined with ABF and PET will be used as the design hypothesis elements, and four different supply chain scenarios was designed for system dynamics and discrete event simulation. The four scenarios supply chain model is compared and analysed against the previous single directional models, and the resulting cost and carbon footprint scenarios are used to determine the final supply chain model's implementation ability.

2. MODEL CREATION

2.1 Conceptual model

2.1.1 Stakeholders

Stakeholders are defined as "individuals and organisations who are actively involved in the project, or whose interests may be positively or negatively affected by the project's execution or the outcome of the project's success" (Project Management Institute, 2021). For a project to be executed successfully, stakeholder analysis can assist in understanding the relationship between stakeholders and the extent to which they influence the project's development (Kapiriri & Donya Razavi, 2021).

There were 14 key stakeholders (Tiwari et al., 2023) environment authorities, agriculture authorities, environment organization, UK government, Mexico government, customs, retailer, cargo company, composite material manufacturer, packaging manufacturer, product manufacturer, raw material collection, raw material factory, Ltd. Company (Fritz, 2022). The company, and the leading customer group distributors in the supply chain.

As the relationship between stakeholders cannot be perfectly balanced (mainly when a wide range of stakeholders are involved), each stakeholder is not in a different quadrant of the stakeholder matrix map. The degree of power and interest in this study (Fig. 2) determined each stakeholder's importance that will help reach a consensus when critical decisions are needed (Kapiriri & Donya Razavi, 2021) and will inform future business models.

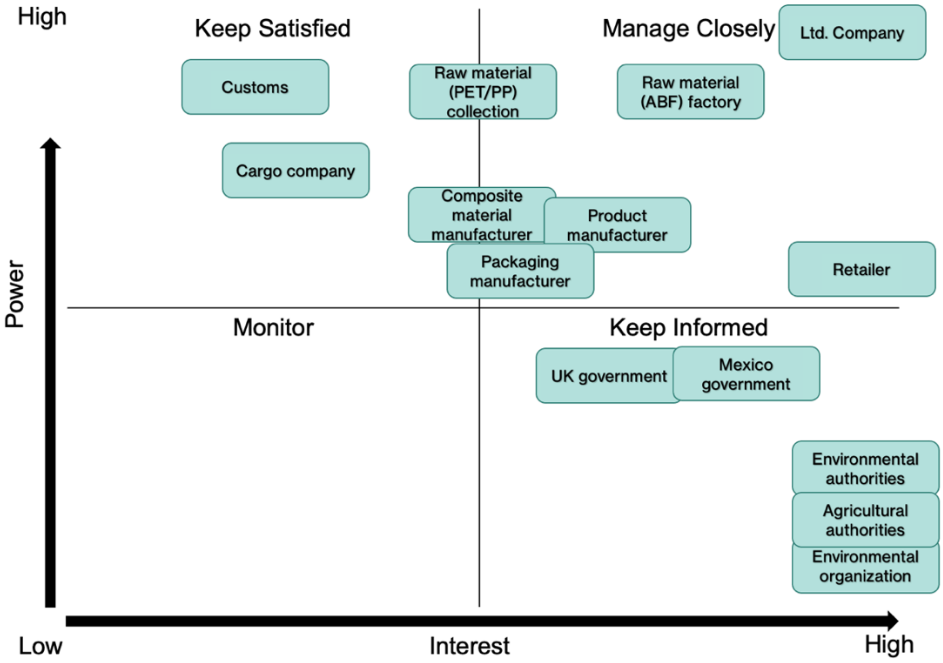


Figure 2. Stakeholder matrix mapping

As shown in Fig. 2, stakeholder matrix mapping showing that government institutions, x-axis shows the stakeholder's interest level in this supply chain process, y-axis is the power of the stakeholder has in the supply chain process.

Secondly, based on the above analysis of the stakeholders, determined the essential relationships between the main stakeholders assist in the subsequent design of the supply chain model (Boruchowitch & Fritz, 2022). Fig. 3 shows, official environmental and agricultural organisations that oversee Mexico, the UK government, and UK customs. These entities will regulate and restrict the raw materials required for the project. Thus, in addition to ABF raw materials, another material combined with ABF will need to be considered for further processing and recycling. Therefore, the supply chain design needs to balance the relationship between stakeholders and the operations of the supply chain. Fig. 3 outlines the flow of the stakeholders in the overall process.

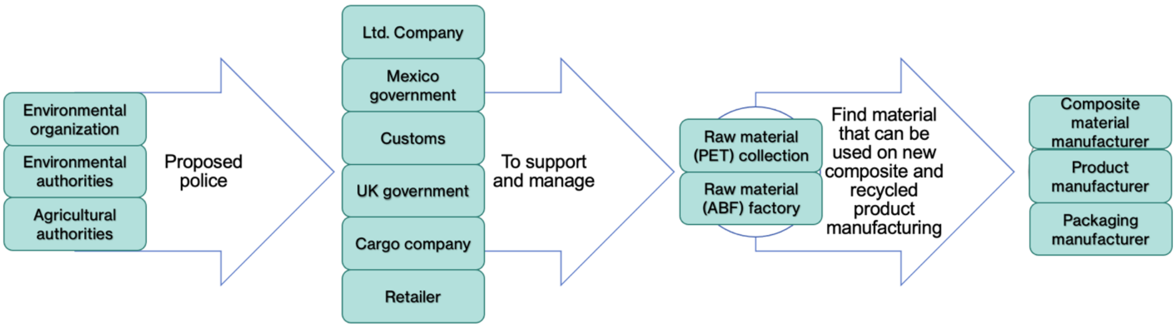


Figure 3. The role of stakeholders in this supply chain

2.1.2 Supply chain concept in model design

With the globalisation of the economy, the economic relationships between countries are getting closer and closer, and the British supply chain experts believe that "the competition in the 21st century is no longer between companies, but between supply chains" (Salhi, 2018). Due to the complexity of the supply chain system, when the mutuality of the factors in the supply chain is ignored, the system will deviate from reality, resulting in the loss of realism, reliability, and value of the supply chain design. The complexity of supply chains is also characterised by multiple loops, linear results, and changes over time (Feng, 2012).

System dynamics and discrete event simulation were used to design and build a supply chain simulation model for this study. In the initial stage of model building, the model was scripted based on the structure of traditional supply chain models in Fig 4, and that was structured and built according to the relationship between stakeholders to make the model more suitable for the needs of the study.

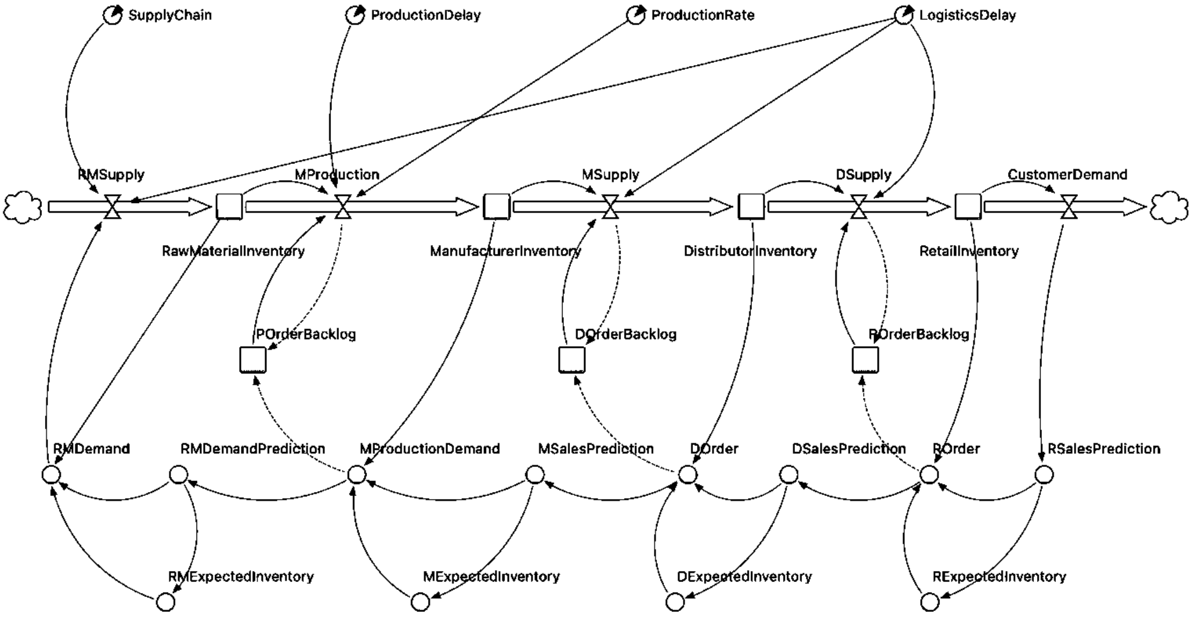


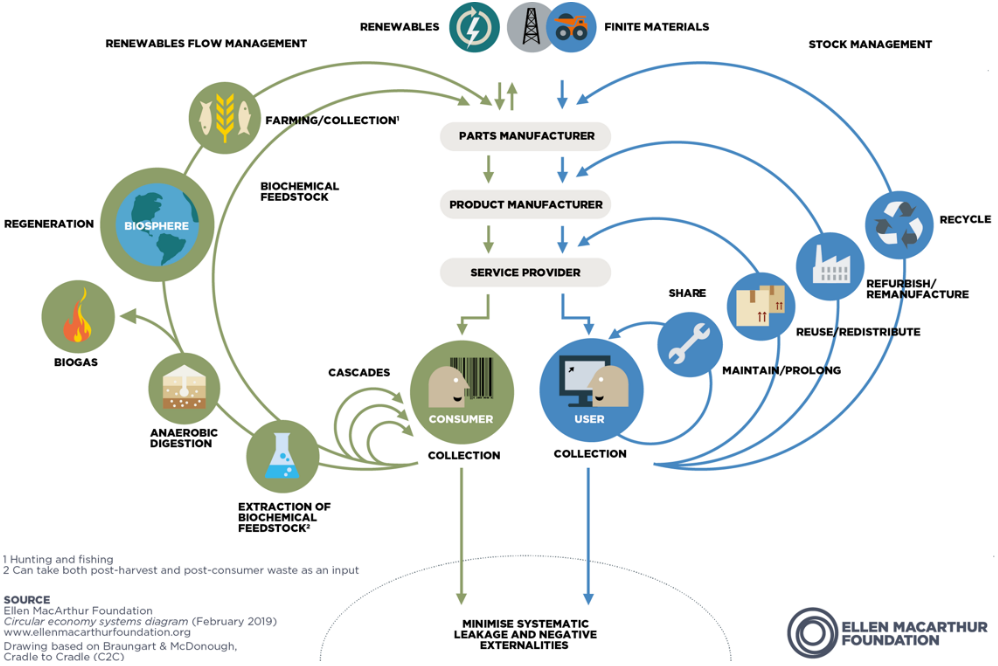
Figure 4. System dynamics traditional supply chain diagram (Zhang et al., 2012)

Secondly, in a sustainable supply chain design, it is very important to balance the relationship between stakeholders in the supply chain. For example, manufacturing capacity and customer demand are two important elements in the supply chain, that can affect and control the number and result of each other. Therefore, the design of supply chain should not only conform to the effective implement ability, but also meet the demand and actual situation as much as possible.

2.1.3 Circular economy principles application for model design

The concept of a circular economy was started in 2010 (Kaur et al., 2018): efficient use of waste, waste minimisation and sustainable development (Bhubalan et al., 2022). The main aim of a circular economy is to keep the manufacturing process sustainable by maintaining the lifetime of material and reduce the loss of consumables (Londoño & Cabezas, 2021). It includes sustainability, materials, energy efficiency and reduced carbon emissions as its primary concerns. A recent trend in green and sustainable energy has brought forth the idea of reducing plastics and the increased use of renewable energy sources, this replaces the one-way linear extraction-processing-consumption-processing process and maintains the value of the product, material and re-source from an economic point of view (Kaur et al., 2018) , such as the development of products made from harmless materials and the concept of circularity have been achieved by using materials that can be returned to the biosphere or back to the market to reduce waste (Nature, 2021). The conceptualisation of these methods be serviced to the project and supply chain management. Therefore, selecting waste plastics as an alternative material (in combination with ABF) to become reusable composites is crucial for our project.

Fig. 5 displays is based on the non-linear process of the circular economy and therefore the model needs to be designed to consider any link in the supply chain that can be manufactured, recycled and reused to maximise the use of waste and maintain circularity. Costs and benefits are also important factors to assess when following the circular economy concept.



1 Hunting and fishing
2 Can take both post-harvest and post-consumer waste as an input

SOURCE
Ellen MacArthur Foundation
Circular economy systems diagram (February 2019)
www.ellenmacarthurfoundation.org
Drawing based on Braungart & McDonough,
Cradle to Cradle (C2C)

Figure 5. Circular economy butterfly diagram (Ellen MacArthur Foundation, 2023)

The standard method used to recycle raw materials ABF and PET is mechanical recycling. But, since the methods and purposes of recycling do not optimize the use of waste and reduce costs, the model of this project is to process and process directly after the recovery of raw materials is completed. In addition, used packaging boxes produced by composite materials combined with ABE and PET are recycled back to the packaging box production plant or the final packaging box packaging plant, thus re-entering the recyclable supply chain, thereby reducing the additional cost of recycling raw materials, transportation, and processing of packaging boxes.

2.1.4 Flowchart of supply chain

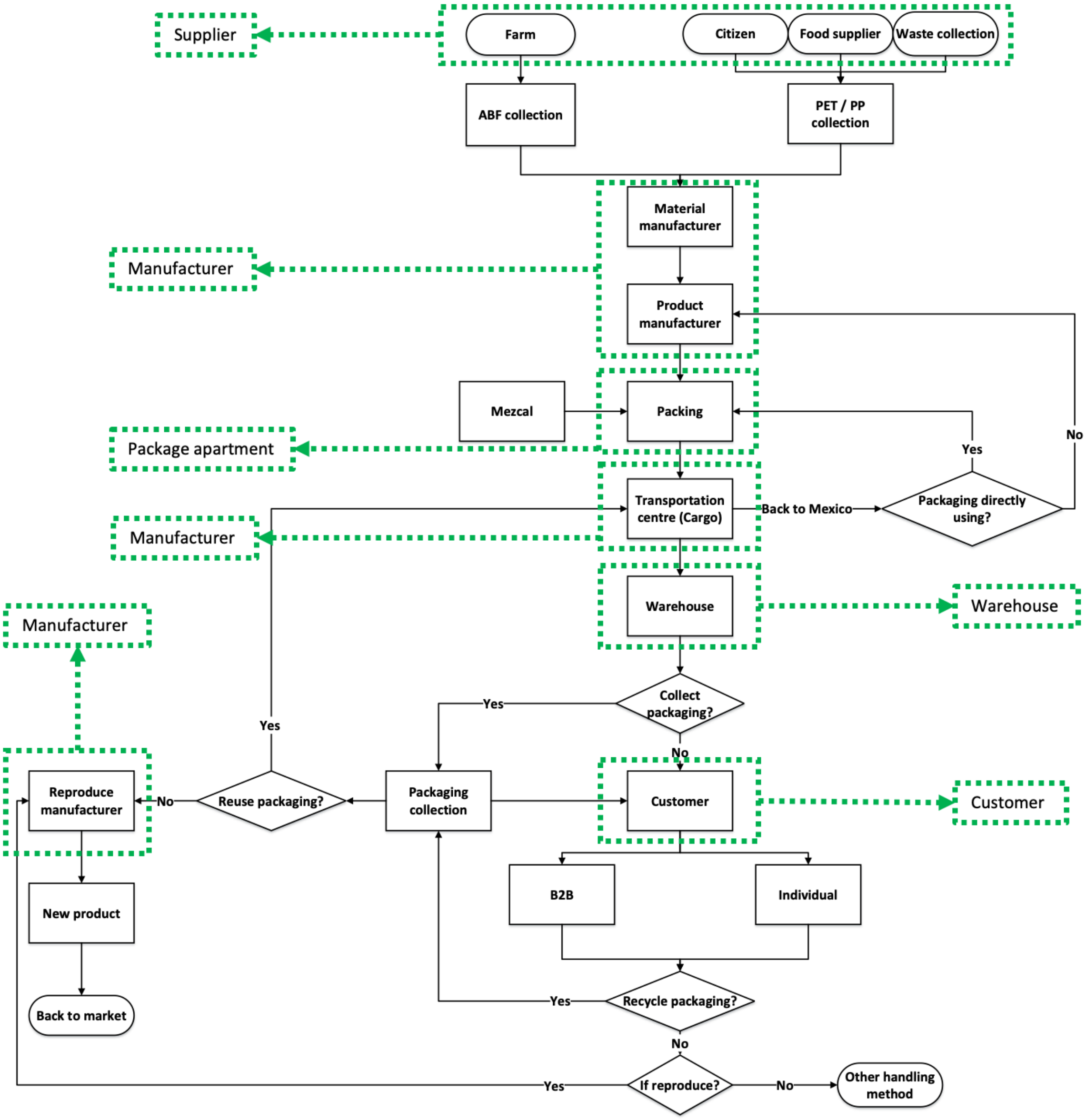


Figure 6. Proposed packaging flowchart for sustainable supply chain

The flowchart shows the complete process designed for the project, starting with collecting raw materials, which is followed by the production of the composite material and the processing plant's production of the final product, which will then be separated and packaged with goods (i.e., the merchandise). The product is then packaged and prepared for shipment by sea from Mexico to the UK. Fig. 6 displays a conceptual flowchart designed considering stakeholders described in Section 2.1.1 governed by supply chain and circular economy principles.

When the goods arrive in the UK, they enter the warehouse, and the finished goods are collected and sorted. Those that can be reused are transported back to the finished goods processing plant in Mexico, while the rest of the finished goods that cannot be reused are reprocessed and put back on the market as raw materials for other products.

The four most basic scenarios for supply chain management were modelled in Section 2.2. The re-launch segment was obtained by calculation in the result.

2.2 Model design

2.2.1 System dynamics and Discrete Event Simulation

System dynamics:
System dynamics is an approach based on feedback control theory that involves solving complex system problems by analysing changes in variables and using computer simulations to reflect real-world causes and effects (Feng, 2012). This approach originated in the early modelling of industrial supply chain problems and has been more widely used in various fields (Dangerfield, 2016), for example, electronics and the automotive industry (Rebs et al., 2019). If uses the working principle of system dynamics to complete the overall design of the supply chain and can obtain guidance for the future development of the supply chain (Dangerfield, 2016). Since system dynamics include designing and analysing changing trends from a macro perspective, simulating system performance, management plans, demand forecasting, and the future possibilities of other events (Tako & Robinson, 2012).

This study model builds upon the concepts and principles of system dynamics, flowcharts and basic models of supply chains, as shown in Fig. 7. The final supply chain model consists of four different supply management options with the overall goal of cost minimisation and sustainability. These programs have different (three) levels of production capacity and customer needs. These different elements are the study variables in each scenario: produced nine annual costs, including transport, production, storage, and recovery costs. The final supply chain solution is determined by the analysis conclusions of the above data results and customer needs. To utilised AnyLogic software to model the system dynamics model used in this study.

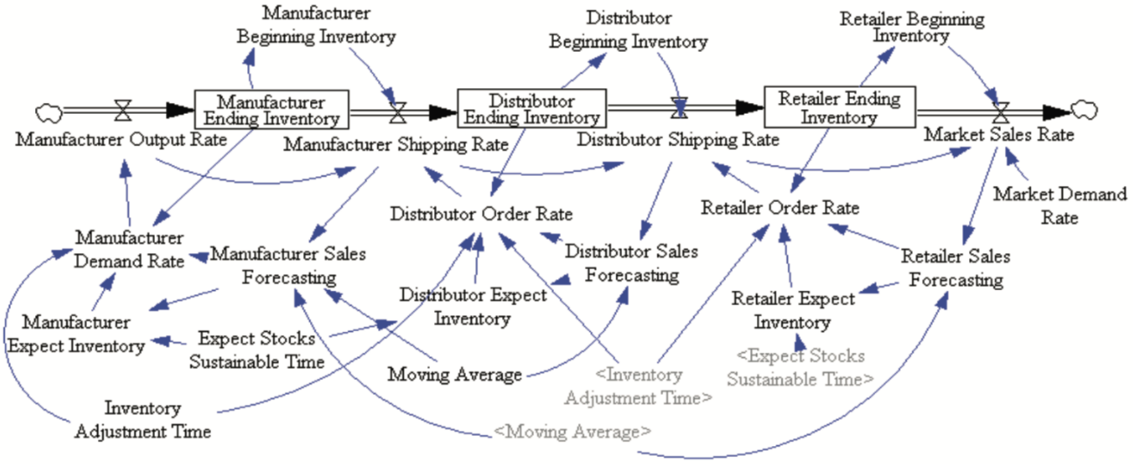


Figure 7. Flow Diagram of Supply Chain Management System before Information Sharing (Feng, 2012)

Discrete Event Simulation:

A discrete system is one in which state changes occur only at discrete times. The state quantities of a discrete system remain constant between two adjacent points in time. Since changes in the state in the discrete system are caused by external "events", the essential properties of the system's activity are reflected in these random but discrete events. The discrete system simulation is also known as discrete event system simulation.

Discrete event modelling is a method of predicting changes in a system based on the pattern of events at discrete points in time. In contrast to the macroscopic nature of system dynamics, discrete event modelling focuses on simulating operational and tactical issues in the supply chain environment, such as distribution and transport planning and supply chain optimisation (Tako & Robinson, 2012). As an event develops, it is analysed and designed by finding a point in time to label changes in the system, such as the point in time when the object of study enters and leaves the system, which is discrete rather than continuous on the timeline, and the system state changes only at discrete points in time.

In this project, the discrete event model was modelled in the same way as the four scenarios of the system dynamics model described above, but with an additional focus on using recyclables as products. This model includes the annual production quantities, which helped calculate the carbon emissions of each scenario. This information also provides customers with more explicit information on these different scenarios. Secondly, the carbon footprint and the number of recyclable products can support and inform future research on materials. The discrete event model for this project was modelled using AnyLogic software.

2.2.2 Parameter setting

In the model building process, the parameter was set for each link in the supply chain to obtain valid data to analyse the results. The parameter value is set in four parts: production, storage, transportation, and recovery costs. In Table 1 summarises every parameter specific setting name with the value.

2.2.2.1 Production costs

The production cost of raw materials and products is based on the cost of local workers in Mexico. According to the latest data, Mexican workers' average cost per hour is £2.11 (Tradingeconomics, 2021). With a working time of 8 hours per workday and five workers on each line producing and processing 100 finished products per day. The cost per finished product produced by the manufacturer is £0.84 for the freight packaging:

$$\frac{£2.11 \times 8 \times 5person}{100} = £0.84/product$$

2.2.2.2 Storage costs

By available statistics, the average monthly cost of warehousing in Mexico is £4.14 per square metre, with an average storage area of 100 square metres and a building height of 8 metres high. The daily storage cost for a warehouse located in Mexico is £13.8 per day.

$$\frac{£4.14 \times 100}{30\ days} = £13.8/day$$

When the finished product arrives in the UK and enters the warehouse for warehousing in cost, the average UK storage cost per square metre is £9041.68, with an average storage area of 100 square metres (Statista, 2021). The daily cost of storage for warehouses located in the UK is £301.40 per year.

$$\frac{£9041.68 \times 100}{30\ days} = £301.40/day$$

2.2.2.3 Transport costs

The logistics cost between the local supplier and the manufacturer in Mexico is £0.78 per kg (Fedex, 2021), and each finished product weighs approximately 1 kg. Therefore, shipping each finished product is £0.78 per unit. The finished product is packed locally in Mexico and transported to the UK by shipping, at an average cost of £1300 (Dfsworldwide, 2021) for a standard 20 ft (43 m^3) container with finished product dimensions: 30 cm*20 cm*30 cm, the average quantity of 2,388 finished products.

$$\frac{43m^3}{(30 \times 20 \times 30) \times 10^{-6}} \approx 2388$$

The cost of carriage per finished product is £0.54 per unit.

$$\frac{1300}{2388} \approx £0.54/product$$

2.2.2.4 Recycling costs

The recycling cost per finished product is £1.38. The finished product is then transported back to the local manufacturer in Mexico through a cargo, reprocessed, and reused. The following diagrams explain the parameter's name, definition, and value in each model.

$$£0.84 + £0.54 = £1.38/product$$

Table 1. Name, meaning, price in the system dynamics model

Parameter name in the model	Description	Value setting
ProductProducCcost / productcost	Product manufacturing fee	£0.84 / product
RawProduceCost / rawproductcost	Composite material manufacturing fee	£0.84 / product
ABFcost / ABFinventorycost	Inventory cost of ABF	£13.8 / day
PETcost / PETinventorycost	Inventory cost of PET	£13.8 / day
RawMaterialCost / semiinventorycost	Inventory cost of composite material	£13.8 / day
InventoryStoreCost / inventorycost	Inventory cost of products in the UK	£301.40 / day
ProductDeliveryCost / productdeliverycost	Cargo costs between Mexico and UK	£0.54 / product
ABFDeliveryCost / ABFdeliverycost	ABF shipping fee	£0.78 / kg
PETDeliveryCost / PETdeliverycost	PET shipping fee	£0.78 / kg
RawDeliveryCost / semideliverycost	Composite material shipping fee	£0.78 / kg
RecyclerTPRent / recoveryrate	Recycle rent of product to packaging	30%
RecyclerTMRent / recoveryrate1	Recycle rent of product to the manufacturer	30%
RecycleTPCost / recoverycost1	Recycle product costs to packaging	£1.38/ product
RecycleTMCost / recoverycost2	Recycle product cost to the manufacturer	£1.38/ product
Productlife / recoverytime	A recycled lifetime of the product	3 times

As the Initial supply chain of Mezcal transportation was in its infancy, there were not enough data sources about the transportation ability, customer demand or other factors of supply chain to support it, so to set up two control variables to obtain more accurate and comprehensive data on the markets involved in the supply chain and future trends of the project.

The control variables were productional ability and customer demand, with three levels: low, mid, and high, corresponding to 2500, 5000 and 10,000, respectively. And utilised different combinations of these values. Each scenario yielded nine results, as shown in Table 2 below.

Table 2. Level matching table of Model result analysis

Control variables		Productional ability		Customer demand	
Parameter name in the model		ProduceRate / productrate		DemandRate / demandrate	
Group	1	2500	Low	2500	Low
	2	2500	Low	5000	Mid
	3	2500	Low	10000	High
	4	5000	Mid	2500	Low
	5	5000	Mid	5000	Mid
	6	5000	Mid	10000	High
	7	10000	High	2500	Low
	8	10000	High	5000	Mid
	9	10000	High	10000	High

2.2.3 Scenario model creation

And based on the stakeholder analysis in Fig. 3 and the conceptual analysis in Fig. 4 and the theory of the model method of the project, four scenarios were designed. In this study, four scenario supply chain models were created using system dynamics and discrete event simulation and following the concept of circular economy and sustainability. Through the concept of circular economy, the use of more circular materials or business models can increase the potential for sustainability, for example by recycling reusable resources to reduce potential environmental or ecological pollution and burdens, effectively avoiding or reducing emissions such as carbon dioxide, and at the same time increasing the efficiency of the business model (Kusumowardani et al., 2022). Using ABF and PET as raw materials, the production of composite materials is based on different proportions of ABF and PET in the model, e.g. 20% ABF and 80% PET. Because of the different proportions of raw materials, which will affect the raw material requirements. The following outlines the different merchandise production activities done for each scenario:

Scenario 1: The raw material collection facility collects the raw materials and stores them in the warehouse. When the composite material manufacturer is short of raw materials, the raw material collection facility transports the required quantity of raw materials to the manufacturer. This scenario will be used as a comparison model with other scenarios to help analyse the data from other scenarios' models and their feasibility.

Scenario 2: The demand of the composite material manufacturer depends on the demand of the product manufacturer. When the packaging manufacturer's stock is insufficient, a request is sent to the product manufacturer's warehouse. When the product manufacturer's warehouse is insufficient, a production signal is sent to the product manufacturer, and if there are insufficient composite materials to be processed, a request is sent. If there is not enough composite material to be processed, a request is sent to the composite material manufacturer's warehouse to obtain sufficient composite material for processing.

Scenario 3: The packaging manufacturer's demand depends on the warehousing capacity of the warehouse. If the warehousing capacity is insufficient to meet the customer's demand, a request is sent to the packaging manufacturer to transport the required quantity of product.

Scenario 4: Used finished products are stored briefly in a recycling depot, and when enough recycled finished products are available, they are returned to the product or packaging manufacturers' warehouses to be used again.

To reduce costs, a warehouse is set up at each stage of the supply chain to ensure that there is no over-collection of raw materials or over-production, which could lead to increased costs (Feng, 2012). Unlike traditional supply chains and other experienced supply chains that have two controllable variables: production capacity and customer demand, there was not enough sufficient data to analyse capacity in this case. As a result, the raw material collection, processing and warehousing of finished goods is controlled by these two control variables when the supply chain model is run.

Following Fig 6, the conceptual flowchart of the supply chain process and the above design details of each supply chain scenario, the following four primary supply chain flow scenarios are identified. The system dynamics scenario in Fig 8, 10, 12, 14 is a more fundamental and macro perspective on the costs and trends of the supply chain, to obtain the result of the annual cost of every scenario. The discrete event scenario in Fig 9, 11, 13, 15 allows for a more accurate annual production of finished goods, for obtain the result of specific predicted number of productions. Furthermore, it includes the annual recycling of finished goods by setting a lifespan for them and calculating a percentage of recycled goods in the total production. This makes it possible to calculate how much the scenario can reduce waste. In this scenario, calculate how much carbon dioxide emissions can be reduced by calculating the proportion of the total recycled production to ensure sustainability.

The scenario's design is the most traditional supply chain design, without the need to recycle the finished product after use and re-operate it in the supply chain. The finished product which has been used is disposed of in a sensible and usually waste treatment method in the UK is by incineration or landfills (Foster et al., 2021), (Ng et al., 2021), (Ng et al., 2019), or to reprocessed as a new product and returned to the market. This entire process would make it a simple, sustainable supply chain.

Scenario 1: Raw material collection - composite material manufacturer - product manufacturer - packaging manufacturer - warehouse - collection inventory - the customer - end deal

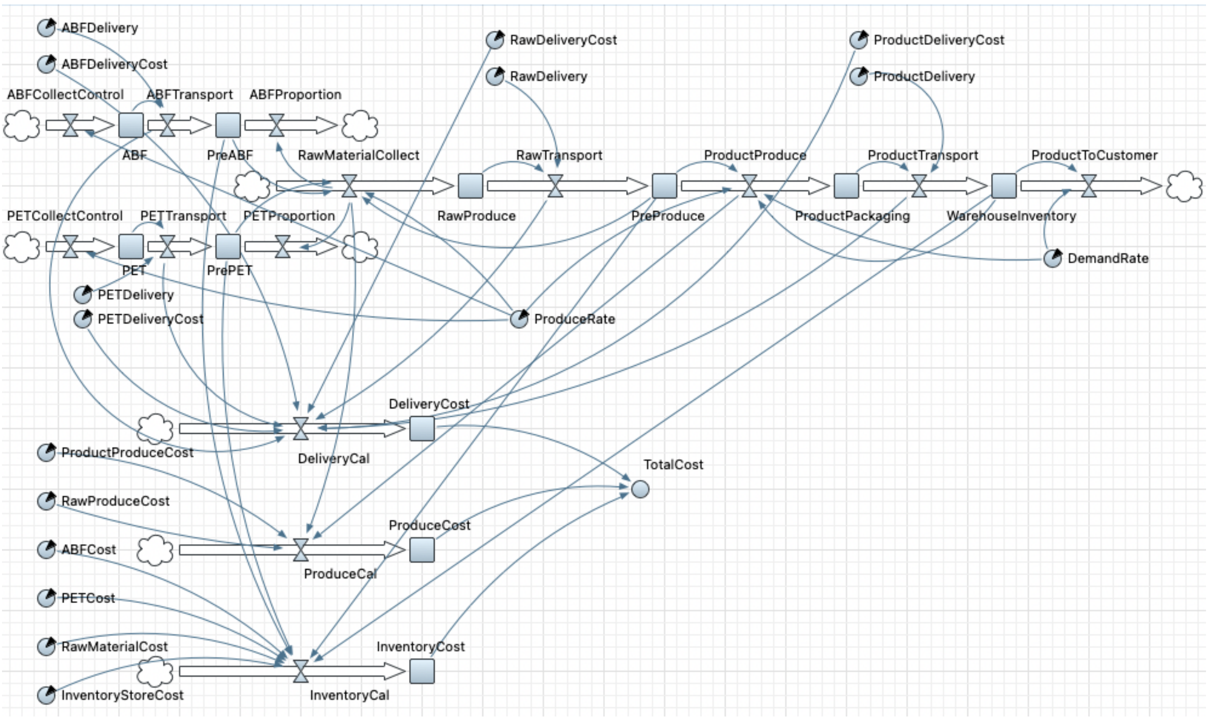


Figure 8. Supply chain model created by System dynamics for scenario 1

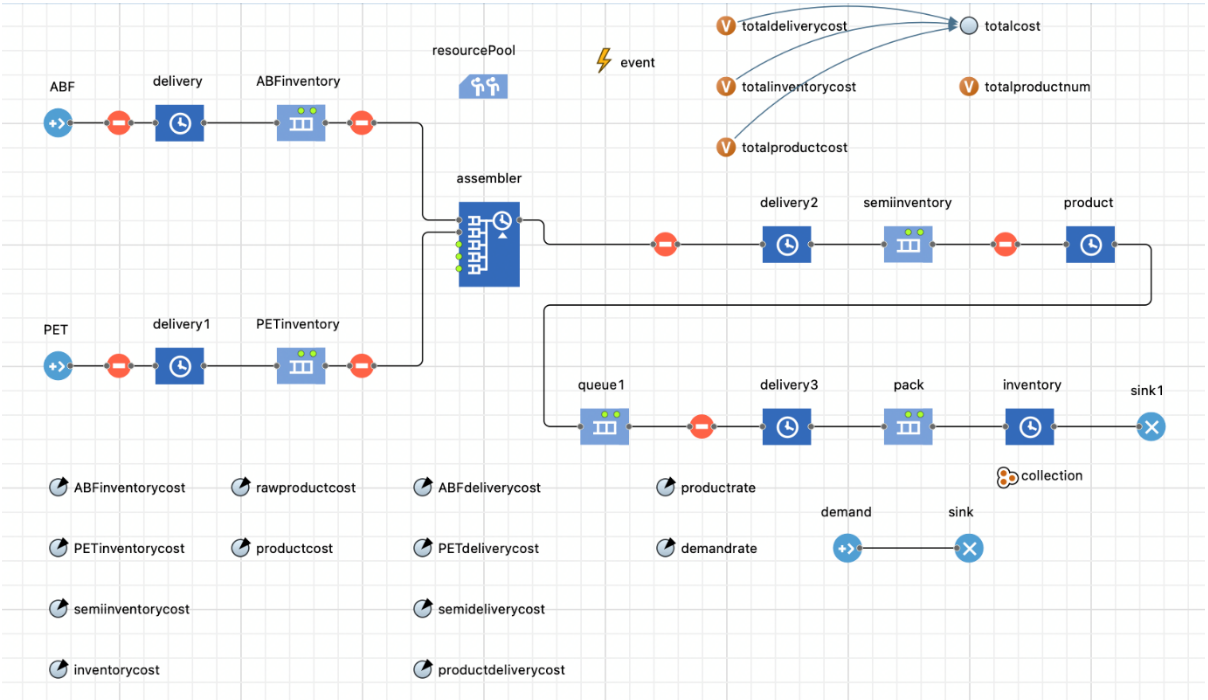


Figure 9. Supply chain model created by Discrete Event Simulation for scenario 1

In scenario 2, after the finished product has been used, the production facility sorts the product for quality. If it meets the conditions for recycling, the facility recycles the product and transports it back to the local product manufacturer's warehouse in Mexico to be processed and used again in the supply chain. On the other hand, the sorting process is defined as non-recyclable, the material is disposed of reasonably as described in scenario 1 above (through incineration). Because when all the products are returned to the production chain, it will mean that there is a possibility of the products being produced again, the CO_2 emissions may be different compared to the other scenario, observing the costs to be spent and the CO_2 emissions emitted.

Scenario 2.1: raw material collection - composite material manufacturer - product manufacturer - packaging manufacturer - warehouse - collection inventory station - customer - end deal

Scenario 2.2: raw material collection - composite material manufacturer - product manufacturer - packaging manufacturer - warehouse - collection inventory station - product manufacturer - packaging manufacturer - warehouse - collection inventory station ...

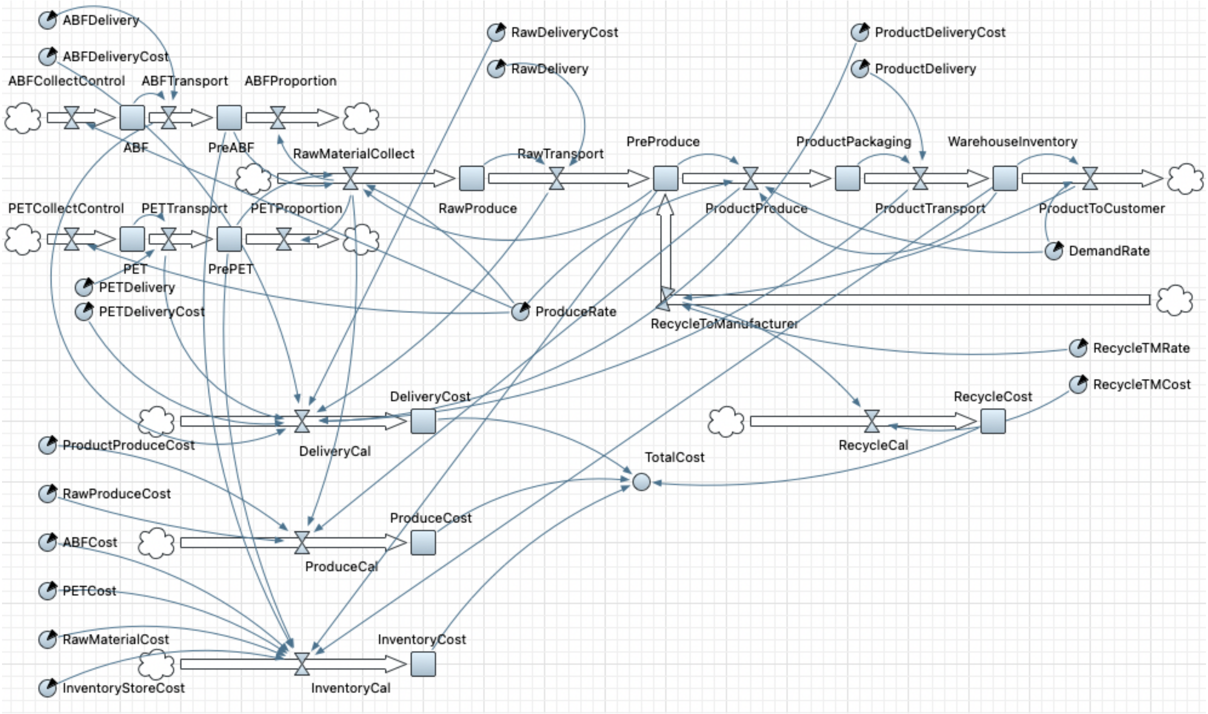


Figure 10. Supply chain model created by System dynamics for scenario 2

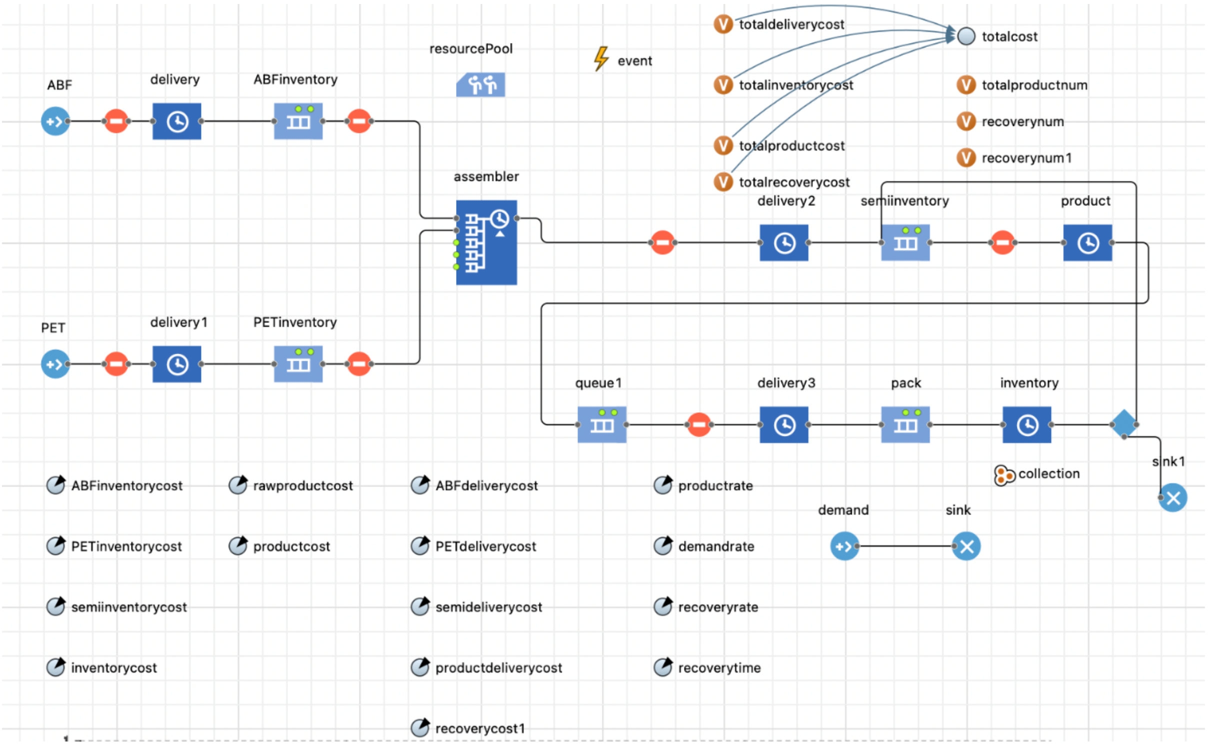


Figure 11. Supply chain model created by Discrete Event Simulation for scenario 2

Scenario 3 is the same process as scenario 2, but when the collection is completed and returned to the local area in Mexico, it is collected directly into the packaging manufacturer's warehouse to be used directly. When all the products are returned to the packing chain, it will mean that the products cannot be produced again and only those that can be used can be selected for reuse, so the CO_2 emissions from handling the finished products that cannot be reused may be different compared to the other scenario as well as the costs that may be incurred.

Scenario 3.1: raw material collection - composite material manufacturer - product manufacturer - packaging manufacturer - warehouse - collection inventory station - customer - end deal

Scenario 3.2: raw material collection - composite material manufacturer - product manufacturer - packaging manufacturer - warehouse - collection inventory station - packaging manufacturer - warehouse - collection inventory ...

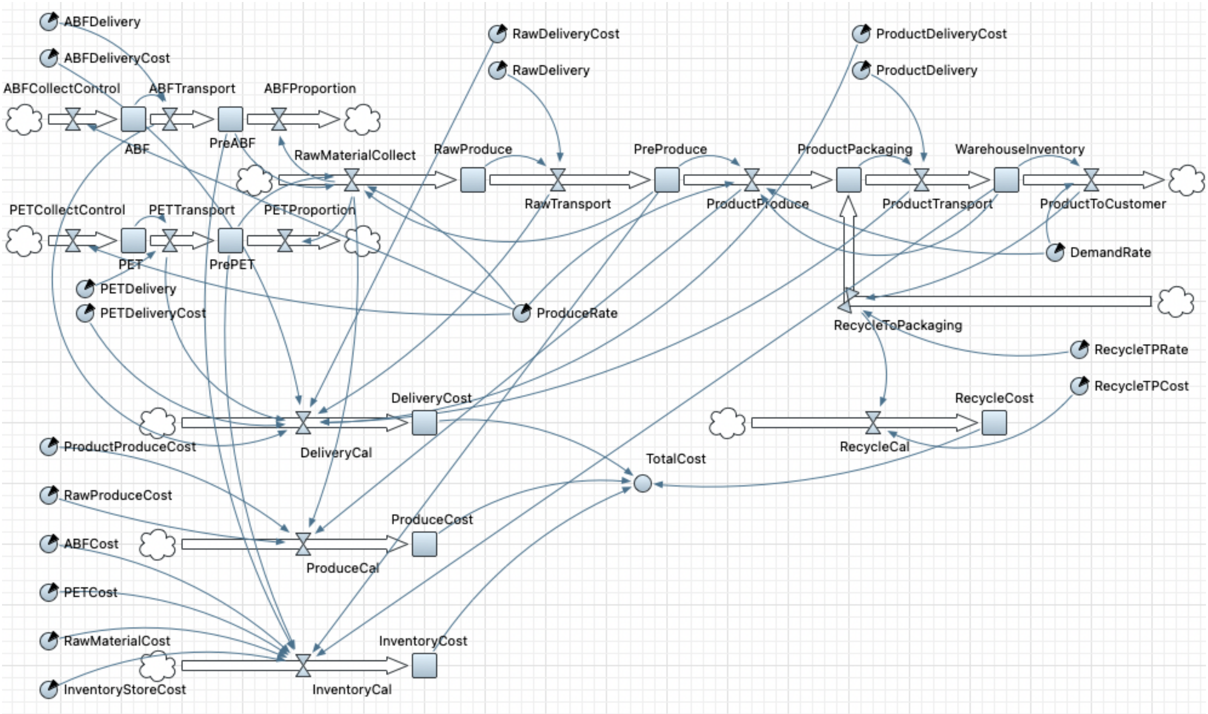


Figure 12. Supply chain model created by System dynamics for scenario 3

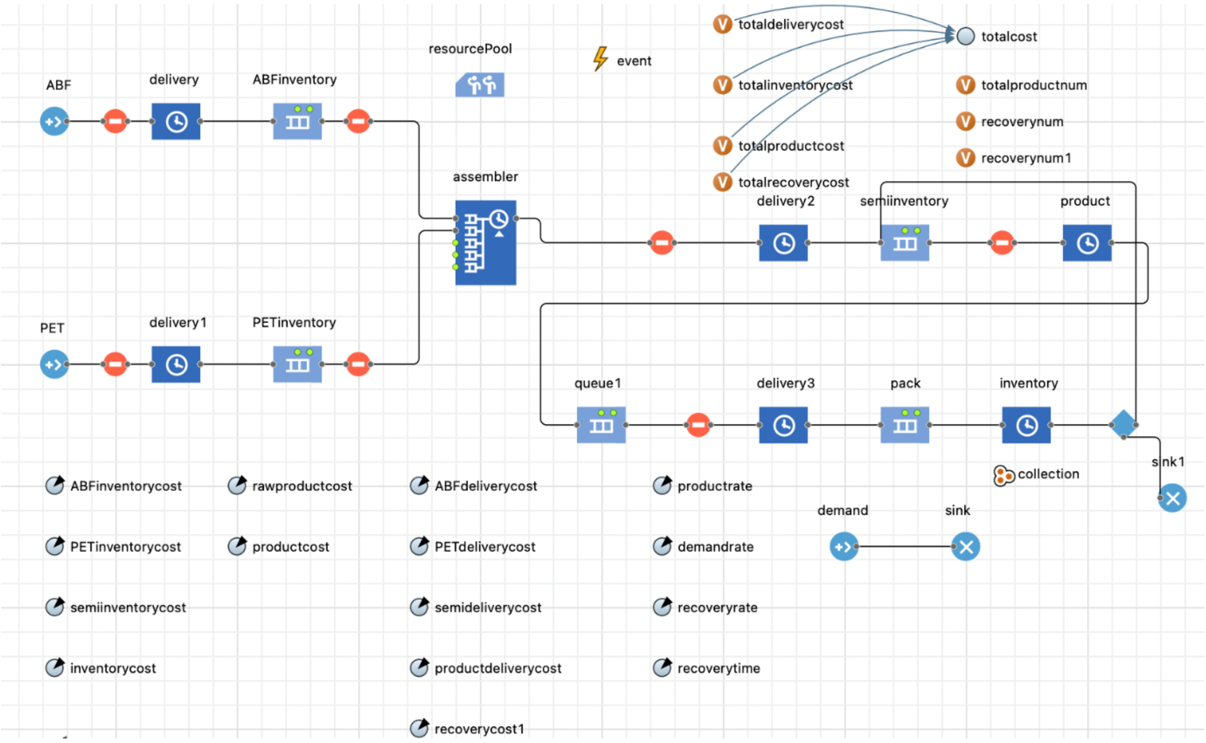


Figure 13. Supply chain model created by Discrete Event Simulation for scenario 3

Scenario 4 combines scenarios 2 and 3 by sorting the finished products according to the quality of the products recycled during sorting and then distributing them to the product manufacturer or packaging manufacturer warehouse. The facility transports the items to a local facility in Mexico. Because all products are already sorted for recycling when they are recycled, avoiding the problem of re-production or the inability to re-produce again may result in a reduction in CO_2 emissions and costs.

Scenario 4.1: raw material collection - composite material manufacturer - product manufacturer - packaging manufacturer - warehouse - collection inventory station - the customer - end deal

Scenario 4.2: raw material collection - composite material manufacturer - product manufacturer - packaging manufacturer - warehouse - collection inventory station - product manufacturer - packaging manufacturer - warehouse - collection inventory station ...

Scenario 4.3: raw material collection - composite material manufacturer - product manufacturer - packaging manufacturer - warehouse - collection inventory station - product manufacturer - packaging manufacturer - warehouse - collection inventory station ...

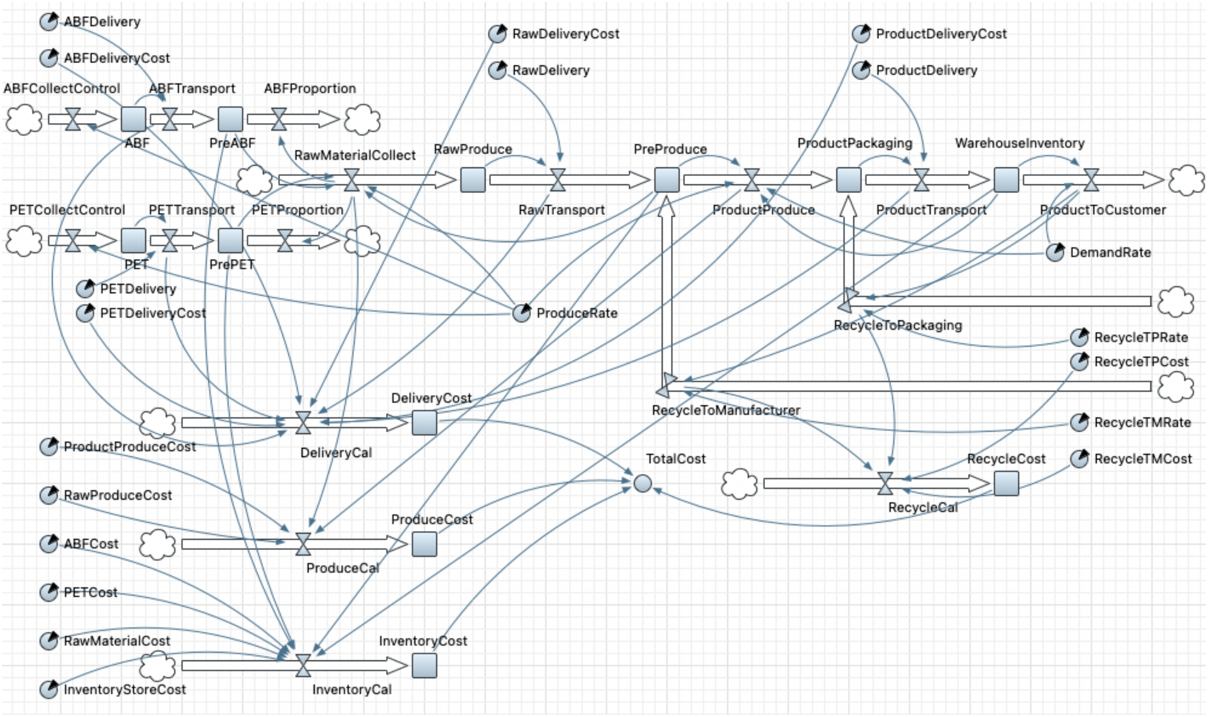


Figure 14. Supply chain model created by System dynamics for scenario 4

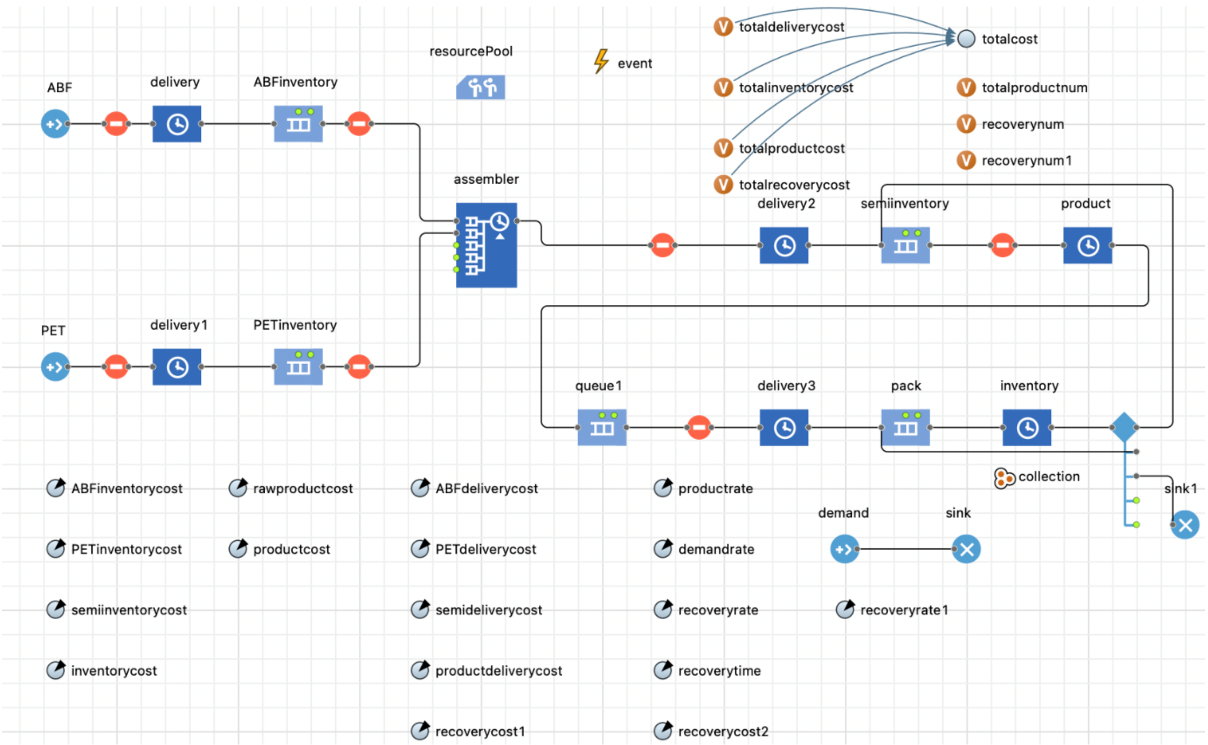


Figure 15. Supply chain model created by Discrete Event Simulation for scenario 4

3. MODEL NUMERICAL EXPERIMENT

3.1 Result analysis

3.1.1 Results for bi-objective supply chain management

The project follows the concept of circular economy and sustainability to create a new design for supply chain management that can reduce the impact on the environment. The annual cost and the saving value of reducing carbon emissions are the primary basis for concluding. Another purpose of our research is to help companies better understand the pros and cons of each situation, such as low cost but long shipping times. The final supply chain design is determined by identifying and comparing the differences between different supply chain models and combining the company's own needs.

In the discrete event model, a specific lifespan of the finished product is set, and then the total number of annual finished products produced is calculated, and the setting of this parameter obtains the total number of finished products recycled. The annual recycling rate is obtained from the number of recycled products below. This formula can show the highest recycling rate achieved when a certain number of control variables are reached. And the result of recycling rate of all scenarios shows on Table 3.

$$\text{recycling rate} = \frac{\text{annual recycled product number}}{\text{total annual product number}} \qquad (1)$$

The reduction in carbon dioxide (CO_2) emissions is calculated by taking the total measured carbon dioxide emissions and the recycling rate. The carbon dioxide emissions from the production and processing of finished products depend on the number of carbon dioxide emissions generated by the raw materials used to produce them. The ABF and PET and the respective ratios of each used in production may change in future studies, depending on the characteristics of the final choice of scenario and further research into the raw materials. And the result of recycling rate of all scenarios shows on Table 3.

$$\text{CO}_2 \text{ emssion saving value}(\text{kgCO}_2\text{e}) = \text{CO}_2 \text{ emission}(\text{kgCO}_2\text{e}) \times \text{ recycling rate} \qquad (2)$$

Table 3. Results of recycling rate and carbon dioxide emission value for all scenarios

Scenario 1

	Total annual product number	**Annual recycle product number**	**Recycling rate**	**CO_2 Emission ($kgCO_2e$)**	**CO_2 Emission saving**	**Total cost**
scenario 1 - 1	30124	-	-	5583670.786	-	£15,990,000.00
scenario 1 - 2	30156	-	-	5589602.185	-	£4,454,000.00
scenario 1 - 3	30165	-	-	5591270.391	-	£4,728,000.00
scenario 1 - 4	35184	-	-	6521573.261	-	£478,700,000.00
scenario 1 - 5	60217	-	-	11161595.53	-	£14,270,000.00
scenario 1 - 6	60300	-	-	11176980.09	-	£8,389,000.00
scenario 1 - 7	41231	-	-	7642422.327	-	£792,400,000.00
scenario 1 - 8	66971	-	-	12413491.44	-	£945,900,000.00
scenario 1 - 9	120688	-	-	22370271.54	-	£42,080,000.00
AVERAGE	**52782**	**-**	**-**	**9783430.839**	**-**	**£256,323,444.44**

Scenario 2

	Total annual product number	**Annual recycle product number**	**Recycling rate**	**CO_2 Emission ($kgCO_2e$)**	**CO_2 Emission saving**	**Total cost**
scenario 2 - 1	30268	6821	22.54%	5610362.081	1264314.78	£37,990,000.00
scenario 2 - 2	30276	6739	22.26%	5611844.931	1249115.57	£27,250,000.00
scenario 2 - 3	30262	6748	22.30%	5609249.944	1250783.776	£30,080,000.00
scenario 2 - 4	34065	7882	23.14%	6314159.651	1460977.73	£488,700,000.00
scenario 2 - 5	60540	13734	22.69%	11221465.59	2545682.332	£64,680,000.00
scenario 2 - 6	60556	13305	21.97%	11224431.29	2466164.513	£59,620,000.00
scenario 2 - 7	39455	8495	21.53%	7313229.679	1574601.093	£817,300,000.00
scenario 2 - 8	66808	15640	23.41%	12383278.38	2898971.288	£998,000,000.00
scenario 2 - 9	121114	26894	22.21%	22449233.29	4984970.194	£120,800,000.00
AVERAGE	**52594**	**11806.44444**	**22.45%**	**9748583.87**	**2188397.92**	**£293,824,444.44**

Scenario 3

	Total annual product number	**Annual recycle product number**	**Recycling rate**	**CO_2 Emission ($kgCO_2e$)**	**CO_2 Emission saving**	**Total cost**
scenario 3 - 1	33840	6673	19.72%	6272454.501	1236882.059	£290,100,000.00
scenario 3 - 2	42912	8991	20.95%	7954006.133	1666537.778	£6,803,000.00
scenario 3 - 3	42820	9011	21.04%	7936953.361	1670244.903	£7,383,000.00
scenario 3 - 4	36362	6990	19.22%	6739922.889	1295639.981	£498,100,000.00
scenario 3 - 5	69241	13526	19.53%	12834250.06	2507128.238	£573,000,000.00
scenario 3 - 6	86542	18235	21.07%	16041098.03	3379970.68	£7,647,000.00
scenario 3 - 7	34657	7408	21.38%	6423890.533	1373118.881	£762,800,000.00

scenario 3 - 8	66959	13886	20.74%	12411267.17	2573856.478	£991,200,000.00
scenario 3 - 9	131533	26702	20.30%	24380459.75	4949381.799	£1,151,000,000.00
AVERAGE	**60541**	**12380.22222**	**20.44%**	**11221589.16**	**2294751.2**	**£476,448,111.11**

Scenario 4

	Total annual product number	**Annual recycle product number**	**Recycling rate**	**CO_2 Emission ($kgCO_2e$)**	**CO_2 Emission saving**	**Total cost**
scenario 4 - 1	32906	10150	30.85%	6099331.791	1881365.638	£318,900,000.00
scenario 4 - 2	42388	12018	28.35%	7856879.474	2227611.058	£39,390,000.00
scenario 4 - 3	42380	11564	27.29%	7855396.624	2143459.334	£41,800,000.00
scenario 4 - 4	42380	11564	27.29%	7855396.624	2143459.334	£41,800,000.00
scenario 4 - 5	69638	20232	29.05%	12907836.48	3750127.053	£629,500,000.00
scenario 4 - 6	85044	23635	27.79%	15763434.41	4380894.271	£76,950,000.00
scenario 4 - 7	34439	13920	40.42%	6383482.877	2580158.589	£782,500,000.00
scenario 4 - 8	66278	24091	36.35%	12285039.58	4465416.708	£965,700,000.00
scenario 4 - 9	136397	42070	30.84%	25282032.4	7797936.196	£1,244,000,000.00
AVERAGE	**61317**	**18805**	**30.91%**	**11365425.59**	**3485603.13**	**£460,060,000.00**

As the annual cost value and the CO_2 emission reduction value are the main factors and references for obtaining the conclusions, the practical way of calculating the weights to specify the importance of cost and CO_2 emissions, and then combining these two results with different weights to obtain the final results, this strategy reduces the complexity of solving multi-objective problems by converting them into single-objective problems (Moshinsky M, 1959), and helps to better analyse the relationship between cost and annual cost and CO_2 emission savings values in the analysis of the model results.

$$\text{result of weight of total annual cost} = \frac{\text{average total cost of sceanrio}}{\sum \text{average total cost of all scenario}} \times \text{ proportion of weight} \tag{3}$$

$$\text{result of weight of } \mathrm{CO_2} \text{ emission saving value} = \frac{\sum \text{average } \mathrm{CO_2} \text{ emission saving value of all scenarios}}{\text{average } \mathrm{CO_2} \text{ emission saving value of scenario}} \times \text{ proportion of weight} \tag{4}$$

Following the data of Table 3 and 4, as the annual cost value and carbon emissions saving value are the main factors and references for obtaining conclusions, different weights are set for these two in the analysis that will help to analyse better the relationship between costs and the annual cost and CO_2 emissions saving value. The average value was obtained by calculating nine different weighted ratios of cost to CO_2 emission reduction.

Table 4. Results of Weighted Values for all scenarios

Scenario 1

Pair of weight (objective #1, objective #2)	**10%, 90%**	**20%, 80%**	**30%, 70%**	**40%, 60%**	**50%, 50%**	**60%, 40%**	**70%, 30%**	**80%, 20%**	**90%, 10%**

Objective #1 (Total cost)	0.0172	0.0345	0.0517	0.0690	0.0862	0.1034	0.1207	0.1379	0.1552	**Average**	-
Scenario 2											
Pair of weight (objective #1, objective #2)	**10%, 90%**	**20%, 80%**	**30%, 70%**	**40%, 60%**	**50%, 50%**	**60%, 40%**	**70%, 30%**	**80%, 20%**	**90%, 10%**		
Objective #1 (Total cost)	0.0198	0.0395	0.0593	0.0791	0.0988	0.1186	0.1383	0.1581	0.1779		
Objective #2 (Total CO_2 Emission saving)	3.2772	2.9131	2.5490	2.1848	1.8207	1.4565	1.0924	0.7283	0.3641		
Scalar objective	3.2970	2.9526	2.6082	2.2639	1.9195	1.5751	1.2308	0.8864	0.5420	**Average**	**1.9195**
Scenario 3											
Pair of weight (objective #1, objective #2)	**10%, 90%**	**20%, 80%**	**30%, 70%**	**40%, 60%**	**50%, 50%**	**60%, 40%**	**70%, 30%**	**80%, 20%**	**90%, 10%**		
Objective #1 (Total cost)	0.0320	0.0641	0.0961	0.1282	0.1602	0.1923	0.2243	0.2564	0.2884		
Objective #2 (Total CO_2 Emission saving)	3.1253	2.7781	2.4308	2.0836	1.7363	1.3890	1.0418	0.6945	0.3473		
Scalar objective	3.1574	2.8422	2.5270	2.2118	1.8965	1.5813	1.2661	0.9509	0.6357	**Average**	**1.8965**
Scenario 4											
Pair of weight (objective #1, objective #2)	**10%, 90%**	**20%, 80%**	**30%, 70%**	**40%, 60%**	**50%, 50%**	**60%, 40%**	**70%, 30%**	**80%, 20%**	**90%, 10%**		
Objective #1 (Total cost)	0.0309	0.0619	0.0928	0.1238	0.1547	0.1857	0.2166	0.2476	0.2785		
Objective #2 (Total CO_2 Emission saving)	2.0576	1.8290	1.6003	1.3717	1.1431	0.9145	0.6859	0.4572	0.2286		
Scalar objective	2.0885	1.8908	1.6932	1.4955	1.2978	1.1002	0.9025	0.7048	0.5071	**Average**	**1.2978**

From the above Table 4, it can be concluded that by average weighted value:

$$1.2978 < 1.8965 < 1.9195$$

$$\text{Scenario 4} < \text{Scenario 3} < \text{Scenario 2}$$

There is no carbon saving value for scenario 1, as there is no recycling operation, and it has no meaning in calculating the weights. Therefore, no comparison was made with the other three scenarios.

Table 5 provides a more transparent comparison of the total cost and CO_2 emission values for each scenario at different weighting ratios and can also provide future customers with a reference on the impact of both in the supply chain. In this table, scenario 4 is the optimal choice for any weighting ratio, while scenario 2 is the second choice and scenario 3 is the third choice when the weighting ratio for total costs is not more than 50%, and vice versa. So, when choosing between scenario 2 or scenario 3, it is necessary to refer to the weighting ratio.

Table 5.Ranking by Weight Value

Pair of weight (objective #1, objective #2)	**10%, 90%**	**20%, 80%**	**30%, 70%**	**40%, 60%**	**50%, 50%**	**60%, 40%**	**70%, 30%**	**80%, 20%**	**90%, 10%**
Rank 1 (scenario)	4	4	4	4	4	4	4	4	4
Rank 2 (scenario)	3	3	3	3	3	2	2	2	2
Rank 3 (scenario)	2	2	2	2	2	3	3	3	3

3.1.2 Results for various production and demand levels

Predicting future trends is also crucial for projects during the start-up phases. Unlike discrete event simulation, system dynamics models allow for a more macroscopic analysis of supply chain operations and future trends. The savings value involves weights based on total annual costs and carbon emissions. To more effectively ensure that the final supply chain solution is based on practical judgments, the discrete event simulation simulates the more realistic benefits of supply chain operations.

The system dynamics model compares nine sets of values for each scenario and further compares them based on the results of discrete event simulation. System dynamics' data analysis is carried out by comparing the total annual cost of the nine sets of cross-sectional data obtained in each scenario.

Fig. 16 shows the supply chain operation of scenario 1 the costs increase when the production capacity is greater than the customer demand. When the production capacity is too large and the customer demand is too small, the demand for the finished product does not cover the production cost. The supply chain will operate precariously in future developments with a similar situation. The costs of overproduction (e.g., excess raw materials and labour) must be reduced. Cost trends are more stable when production capacity is balanced with customer demand or when production capacity is lower than customer demand. When the two control variables are stable, the business operation is also stable, and the projected trend is good.

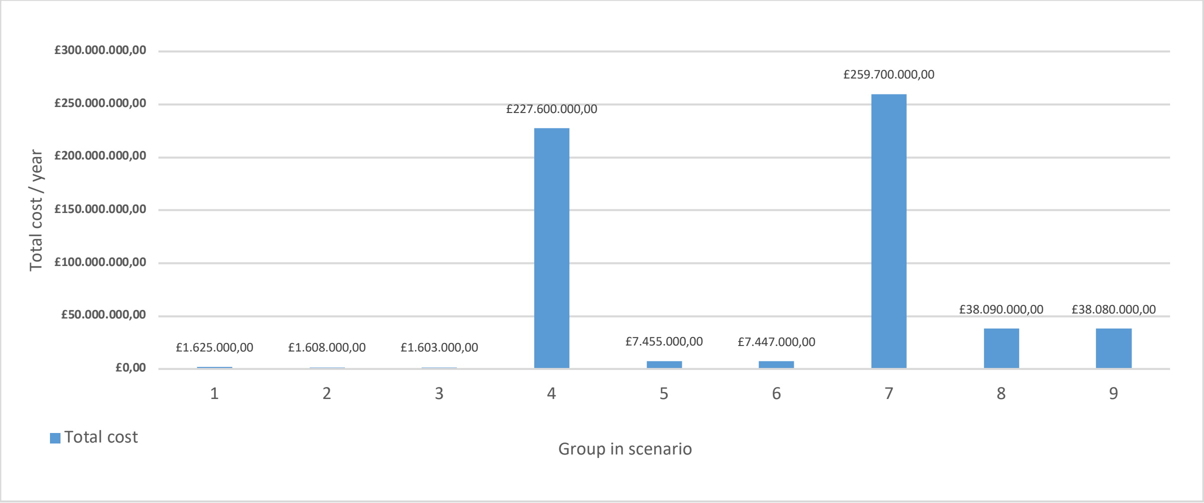


Figure 16. Total cost of 9 groups for Scenario 1

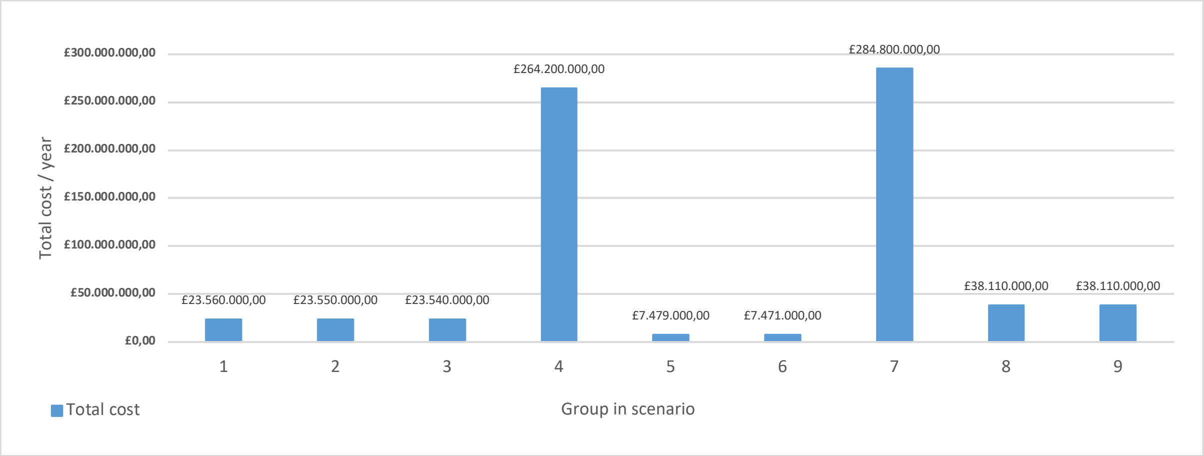


Figure 17. Total cost of 9 groups for Scenario 2

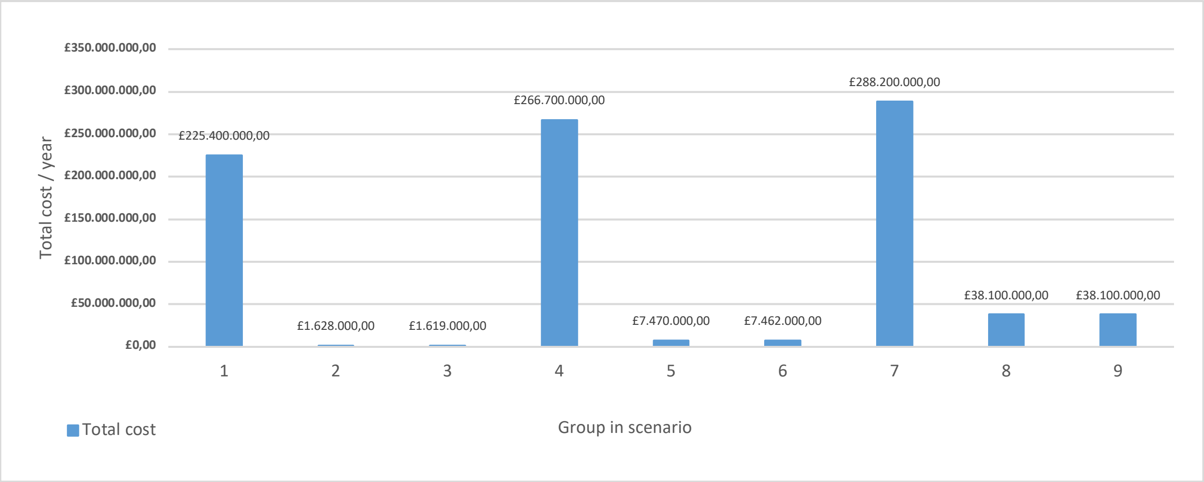


Figure 18. Total cost of 9 groups for Scenario 3

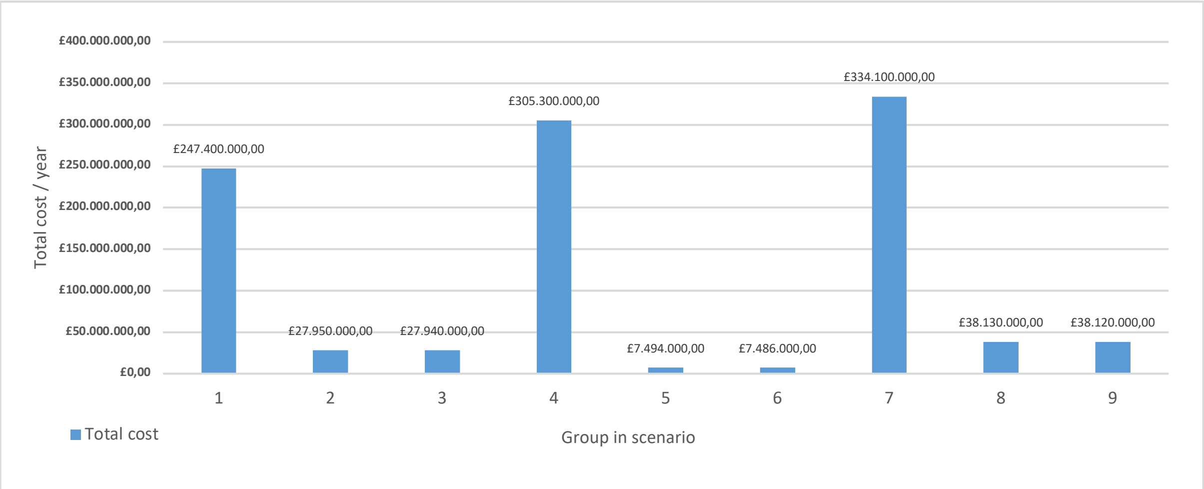


Figure 19. Total cost of 9 groups for Scenario 4

The analysis of the results in Fig. 17 – 19 for the remaining three scenarios was the same as for scenario 1 above.

The average total cost of the nine data sets for each scenario was calculated, and the average total cost of the four scenarios was compared and analysed, as shown in Table 5.

Table 6. Average total annual cost for the four scenarios by system dynamics

	Average Total Annual Cost
Scenario 1	£64,800,888.89
Scenario 2	£78,980,000.00
Scenario 3	£97,186,555.56
Scenario 4	£114,880,000.00

To the analysis results in Table 6, scenario 1 has the lowest total cost and scenario 4 has the highest total cost.

About the discrete event simulation results above, scenario 3 is an alternative solution, but according to the more visible system design results, scenario 1 has the lowest total costs. Because the design in scenario 1 does not require recycling of the finished product, recycling costs are incurred.

Run through simulations of system dynamics and discrete event simulation models. Based on the data results mentioned above analysis, the discrete event simulation analysis shows that scenario 4 has the lowest weighted result value and performs well in terms of total annual costs and CO_2 emissions. In the system dynamics results, scenario 4 has the highest total annual cost because scenario four is designed so that the finished product is first sorted for quality, and according to the recyclability criteria, the finished product is then recycled to a local finished product manufacturer or a facility in Mexico.

Secondly, although scenario 4 has a high-cost value, a macroscopic analysis shows that the total costs are higher when the two control variables (i.e., production capacity and customer demand area) are equal and stable. Secondly, although the total cost value in scenario four is too high in system dynamics, production capacity and customer demand area directly relate to cost. In other words, when production capacity and customer demand area are flat and stable, total costs will also tend to be stable. Combining the results of the calculations and analysis of the model data above, and in following the economic concepts in the circular economy, scenario 4 is the optimal solution for the sustainable supply chain management.

4. DISCUSSION

The project used system dynamics and discrete event methods to design and obtain data for four scenarios of the supply chain process. These methods were based on the concept of circular economy and sustainability. Based on the results from data analysis and the customer demand for the supply chain, scenario 4 was determined to be the optimal solution.

To compared with the design and analysis results of Feng's (Feng, 2012) one-way model, the model focuses on the different results obtained by adjusting and considering the information changes in market demand and determining the interdependencies in the supply chain in turn.

Firstly, to focused on the practical application simulation technique, such as system dynamics and discrete event simulation into to a new field. Secondly, this paper proposes by first time a model for the packaging industry manufactured by agricultural waste. The model is at the initial stage and validation using specific data sets remain as next steps in this research.

In this regard, the four supply chain model scenarios in this study were designed for recycling the overall supply chain based on the original model. At the same time, the supply chain design is completed by introducing supply chain management factors to enhance the practicality, reliability and effectiveness, such as product service life (that is, the number of times the product can be recycled), refining the supply chain links, and sorting differently according to the state and form of recycled waste that is finally needed. Furthermore, return it to the correct supply chain link, thereby increasing the flexibility of recycling and reprocessing to obtain more accurate data results, calculate annual costs and carbon emissions, and determine a more low-carbon sustainable supply chain model. This provides the proposed sustainable supply chain solution a promising future. And because compared to the circularity model, the traditional supply chain model goes in a single direction and does not consider the disposal of the product after it has finished serving the customer and the service life of the product, so the original design and concept of the product may lack the relevant idea to complete the production of the product by reducing the cost as much as possible to meet the immediate needs of the customer, but at the same time of low cost, the production process, but at the same time, the CO_2 emissions generated during the production process will increase as the number of production runs increases. In the case of following the concept of circular economy and sustainability, the traditional supply chain model may not be able to achieve this.

In addition, since there is no relevant article proposing discrete event simulation models to design supply chain models that conform to the concepts of circular economy, it is not possible to compare model designs. But the concept and aim of circular economy helps to improve the flexibility of the model in the simulation operation plan and design, some of the parameter values can be changed according to the needs of future studies, such as the number of raw materials, inventory line or product service life, etc., according to the actual material experiment results to change the parameter value or run multiple different values for the results of the comparison, so using this model and enabling that the material researchers and choose PET or with another material with the confidence that still is the possible thing or is going to be. Finally, according to the comparison of results and requirements, the value of the hypothetical value is determined.

4.1 Sustainable impact

4.1.1 Socio-economical

Sustainable development promotes change concerning the environment, economic efficiency, and social equity, bringing local benefits such as employment opportunities and economic growth (Leal Filho et al., 2018).

There is relatively little research in developing countries on sustainable supply chain initiatives, mainly because there is a lack of enablers for sustainable development. For example, this includes a lack of policy support from local governments and few voices to advise suppliers when trying to start a sustainable business. That also might be related to a lack of development in certain countries that are not well placed to meet their own needs regarding sustainable supply chain management (Jia et al., 2018).

Also, the local situation in Mexico is consistent with the above: the economy, jobs, infrastructure, and sustainable urban development are not equal to other developing countries (Salvia et al., 2019). Therefore, this project considers these circumstances when designing the entire supply chain by placing the core of the product processing in Mexico, which will provide more opportunities for local employment and economic growth. New job opportunities are available at manufacturing plants and waste recycling policies. Regarding -reusing raw materials, a large amount of local agricultural waste (ABF) is used as one of the raw materials. Additionally, consideration is given to combining PET or other plastic waste with ABF to reuse as much waste as possible and improve the secondary environmental damage caused by waste (e.g., carbon emissions from burning waste).

4.1.2 Environmental

In terms of the environment, reusing agricultural waste through reprocessing into renewable recycling items can significantly reduce the greenhouse gases such as carbon dioxide generated by the disposal of agricultural waste and damage to the soil caused through burial (Lupa et al., 2011).

5. CONCLUSION

The conclusions of the supply chain designed above show that ABF and PET are effective and enforceable in combination to form composite materials. By controlling the range of productivity and customer demand rate, predicting the results of cost and environmental impact of the supply chain under different circumstances, and determining that scenario 4 is the optimal solution.

Developed bi-objective decision support tool i.e., system dynamics and discrete event simulation, supports planners in determining the best option for implementing their sustainable supply chain practices which followed the concept of circular economy. System dynamics was used to simulate the flow of products in a sustainable supply chain, while discrete event simulation (based on diffusion theory) was used to define the use and recovery life of the product. By setting the use and recovery life, which will interact with the product developer's expectations and design of the performance of the product itself, while the results iterate over each other, it allows the product developer and the company operator to determine the effective of recycle and minimum cost balance of the product's desired outcomes, e.g., product performance, recovery methods, etc.

Secondly, by analysing the different scenarios of productional ability and customer demand in the model's parameter setting, companies can better understand each scenario's costs and carbon dioxide emissions and future developments, to determine the optimal scenario.

By following the concept of circular economy to achieve this sustainable supply chain can provide more practical reference factors for further material research, such as cost, transportation, carbon footprint, etc., and attract the sustainability of the supply chain in the industry packaging. Secondly, it provides future researchers with system dynamics and discrete event simulation sustainable supply chain models of waste materials and provides a reference for supply chains in other sustainable fields. But integrate the standard model into the circular economy thinking and experience will be considered.

Although further research into materials is needed, the preliminary findings of this study can help with subsequent studies, as the overall methodology and supply chain framework of the project has been established. For subsequent studies on materials in the supply chain process, it is only necessary to use the ideas, methods, and models to make the final material selection. For subsequent studies on materials in the supply chain process, it is only necessary to use the idea of sustainable and economy, Double-Diamond method of methodology and system dynamics and discrete event simulation of models to make the final material selection. Additionally, future researchers can modify the design and product design based on the properties of the materials being used. In the further research, the whole framework design. The supply chain model can be iterated with subsequent material experiments and whole framework design, allowing the model to be validated and the accuracy and veracity of the model's design conclusions to be improved.

In addition, the production of new green composite materials from ABF and PET as experimental hypotheses is an ideal concept. The combination of ABF and recycled PET is an important direction for future research, such as looking for other materials that can be matrix-compatible and can be substituted into other sustainable research material.

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AUTHOR CONTRIBUTIONS

Jia Yu: : investigation, data curation, visualization, methodology, writing original draft.
Trung Hieu: funding acquisition, conceptualization, methodology, review and editing
Simon Gray: conceptualization, supervision, methodology design, review and editing.
Adriana Encinas-Oropesa: conceptualization, supervision, methodology design, visualization, review and editing.

DECLARATIONS

Competing interests: The authors declare no competing interests.

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