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The Dynamics of Sustainability Risks in the Global Coffee Supply Chain: A Case of Indonesia–UK

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Abstract: Indonesia is one of the leading global coffee producers, and the sustainability of its coffee supply chains is therefore of crucial importance, not only for the coffee sector, but also for the thousands of livelihoods involved. Recognising sustainability risks within supply chains is an important component of understanding logistics. This research investigated the sustainability risks in the Indonesia–UK coffee supply chain by using System Dynamics (SD), a simulation modeling paradigm commonly used to assess complex systems. The model parameters and other components of the dynamic model were extracted through interviews with key stakeholders in the coffee supply chain, supported by evidence from a literature review. The model was then verified and validated in different stages, before being used to investigate five different what-if scenarios to consider changes to parameters in the system. The results of this investigation demonstrate the importance of improving agricultural productivity to support a sustainable coffee supply chain. This research also confirms that by combining the SD model and the multiple criteria decision-making technique, it is possible to achieve a more practical and accurate solution than by the individual tool alone, thus ensuring a better understanding of the whole issues affecting the coffee supply chain.

Keywords: system dynamics; multiple criteria; sustainability; risks; coffee supply chain

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1. Introduction

Sustainable coffee is grown in a way that not only preserves nature but also leads to a better livelihood for all those involved in the coffee production industry. Coffee is grown almost exclusively in the tropics, so one of the easiest ways to expand the plantation for the coffee is by cutting down the trees in the surrounding forests. Water wastage during the processing of coffee is another aspect which prevents nature from being conserved [1]. The coffee supply chain includes different stages, starting from coffee production by the farmers, to collection, storage, processing, distribution, export, import, roasting and retail. The emergence of risk factors in every stage of the coffee supply chain may threaten its sustainability in any one of the economic, environmental, or social aspects.

Indonesia is one of the major players in the global coffee industry, producing around 12,000,000 60-kg bags of coffee in the period of 2018–2019 [2]. An important market for Indonesian coffee is the UK. Indonesia is the third largest supplier of green coffee beans to the UK (15% of market share), behind Vietnam (22%) and Brazil (21%) [2]. However, the volume of coffee being imported from Indonesia in the last five years has not been consistent and rather unpredictable (Figure 1), which raises questions about the sustainability of its future. For this reason, the study described in this paper aims to investigate the sustainability risks of the Indonesia–UK coffee supply chain.

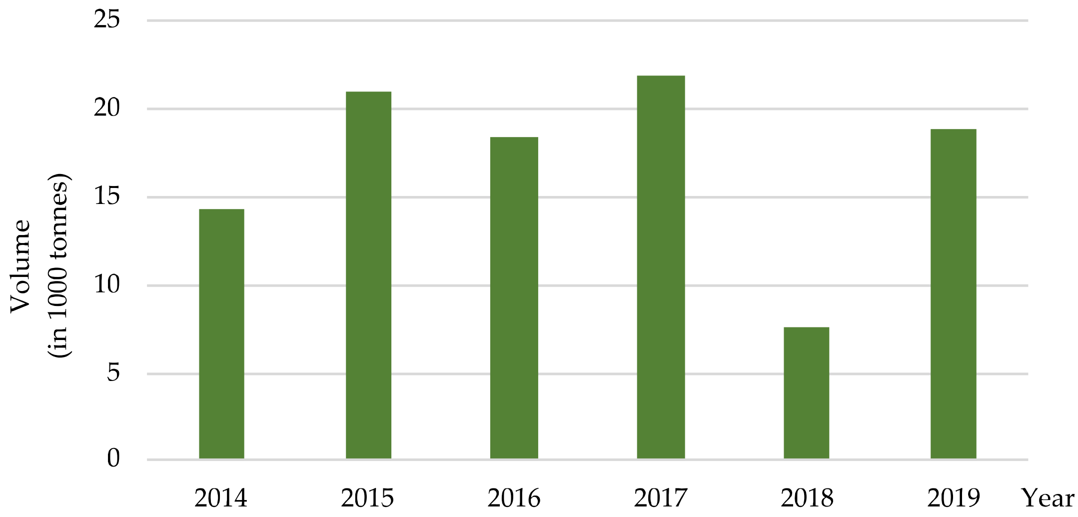

Figure 1. Coffee imported to the UK from Indonesia, 2014–2019. Source: [3].

Sustainability risks include any types of risk which may affect the economic, environmental, or social aspects. So, any factors which can threaten the coffee market (and especially the international market) can be considered as risks to sustainable coffee. This also includes other factors which affect the natural resources, the environment, the livelihood of farmers, as well as other people who benefit from the coffee supply chain.

In order to assess the impacts of sustainability risks on the coffee supply chain, a System Dynamics (SD) modeling approach has been chosen. SD is a form of quantitative analysis that allows the examination and simulation of complex and dynamic systems "to support long-term, strategic decision making" [4]. It follows a Systems Thinking approach [5] to understand societal problems, by appreciating their interconnected nature. The area of sustainable supply chain management has seen much engagement with SD modeling [6] as it allows an investigation into various changes of input parameters of the supply chain over time, resulting in a certain output performance. Previous studies also confirm the appropriateness of SD in various business applications (see Table 1).

Table 1. Summarised review of recent SD applications in various business sectors.

SD Applications	References
Construction systems	[7]
Energy efficiency	[8]
Urban resilience	[9]
Oil import system	[10]
Mobile payment	[11]
Reverse supply chain on electric vehicle batteries	[12]
Municipal solid waste management	[13]
Manufacturing systems	[14]
CO_2 emissions in the cement industry	[15]
Health sciences	[16]
Water resources modeling	[17]

Rebs, Brandenbury, and Seuring [4] reviewed various SD models in sustainable supply chain management focusing on transportation, manufacturing, logistics, life-cycle analysis, and renewable energy. A core component is the ability to model feedback loops, comprehending how factors play out and have implications for the wider system according to the parameters entered and the conditions under which a test is run. A process of scenario building is a common feature of such studies, which involves the simulation of predicted events.

Some notable studies employing SD in the area of coffee supply chains can be found in the literature. Jaya et al. [18] and Hakim et al. [19], for example, developed supply chain models of the Gayo coffee supply chain and investigated various factors that were critical to its sustainability. The models were used to assess how the actors of the supply chain can increase the adding value of the coffee. Similarly, Caliari and Bueno [20] studied the Brazilian coffee supply chain and explored the effects of price protection policies on the coffee production. This study outlines the development of the SD model to explore the sustainability risks to the Indonesian–UK coffee supply chain. The purpose of using the SD model is to develop a comprehensive understanding of the different factors that exert an influencing role on the supply chain (with respect to sustainability risks) and to investigate the influence of both individual factors and scenarios with multiple criteria.

An important point to note is that SD models allow a flexible working of model scale. Whilst the supply chain of coffee exported from Indonesia to the UK is the macro remit of this research, an SD model opens up various opportunities to model specific points within this supply chain. For example, an important metric differentiating coffee markets is the amount of coffee being harvested by farmers, the amount of coffee exported and the amount sold domestically. For each of these outputs, the SD model allows factors to have a varying level of influence. This means that a model can simulate the influence of factors over these micro level parts of the supply chain. This can be in the form of parameter values that can be controlled, such as the level of compliance with regulations, as well as variables that are not under control, such as the impact of climate change. It is the relationship between these different types of factors over time, and the influence they hold both in specific parts and the whole remit of the supply chain, that can be accessed through SD modeling.

A starting point in the model development was to first understand the risks associated with the sustainability of coffee supply chains. A two-stage preliminary investigation has been undertaken to extract the risk factors via empirical studies involving coffee supply chain stakeholders. In the first stage, a survey and an interview were conducted with the coffee stakeholders in the UK and then, in the second stage, this was repeated with the coffee stakeholders in Indonesia. A review of the extant literature was carried out to validate the risk factors of the sustainable supply chain obtained from the empirical study. The combined risk factors are listed in Table 2, showing where the information originated, the types of risk (economic, social, or environmental) and the relevant references. Collating these risks was an iterative process. By carefully defining the risk factors, it is possible to substantially justify the knowledge creation, where numerical values could be assigned as measurable or quantifiable model components.

This paper is organised as follows. The research method, the SD model and its components, and the development stages are explained in Section 2. The results of the analysis are reported and evaluated in terms of verification and validation, and scenario analysis in Section 3. Discussion about this research is presented in Section 4 and finally, the paper is concluded in Section 5.

Table 2. Extracted risks of the sustainable supply chain to be used in the SD models.

Risks	Source	Types of Risk	References
Price of coffee	UK Interviews, Indonesia Workshop	Economic	[21–25]
Quality of coffee	UK Interviews, Indonesia Workshop	Economic	[21–27]
Climate change and agriculture related issues	UK Interviews, Indonesia Workshop	Environmental	[21,23–25,27–30]
Trade policy of Indonesia and UK and other regulations	UK Interviews, Indonesia Workshop	Social	[21,23,31]
Labor supply and farming livelihoods and suppliers' employment practices and policy and employee job dissatisfaction	UK Interviews, Indonesia Workshop	Economic	[23,25,28,31–33]
Availability of processing facilities and continuity and disruptions	UK Interviews, Indonesia Workshop	Economic	[21,24,25,30]
Changing consumption patterns and order fluctuations	UK Interviews, Indonesia Workshop	Economic	[25,32]
Consistency of supply	UK Interviews, Indonesia Workshop	Economic	[17,21,28]
Capacity of supply	UK Interviews, Indonesia Workshop	Economic	-
Timeliness of supply	UK Interviews, Indonesia Workshop	Economic	[21,23–25]
Transportation		Economic	[25]
Exchange rate and currency fluctuation		Economic	[23,25,32]
Shortage or un-fulfilling the orders and obsolescence		Economic	[25]
Product and packaging wastes		Environmental	[23,28,31]
Energy consumption		Environmental	[23,28]
Land use and ecosystem		Environmental	[23]
Risks of mitigating greenhouse gas emissions or recycling and environment impact		Environmental	[23,25,28,31,33,34]
Unethical behaviour of suppliers		Social	[35–38]
Workplace, health and safety		Social	[23,25,28,31,33]
Child or forced labor	UK Interviews, Indonesia Workshop	Social	[23,28,31]
Discrimination (race, sex, religion, age, politics) and Unethical behaviour of suppliers	UK Interviews, Indonesia Workshop	Social	[23,28,35–38]
Inhumane treatment or harassment	UK Interviews, Indonesia Workshop	Social	[23,28]
Unethical treatment of animals	UK Interviews, Indonesia Workshop	Social	[28]
Excessive working time or work-life imbalance	UK Interviews, Indonesia Workshop	Social	[28,31]
Demographic challenges or ageing population	UK Interviews, Indonesia Workshop	Social	[28]
Pandemic	UK Interviews, Indonesia Workshop	Social	[28,39,40]
Social instability or unrest	UK Interviews, Indonesia Workshop	Social	[28]
Compliance with local and (inter)national laws and regulations and supply constraints	UK Interviews, Indonesia Workshop	Social	[21,23,31]

2. Materials and Methods

In this study, an SD model is developed to consider the government's as well as other key stakeholders' viewpoints, which may impact on the Indonesia–UK coffee supply chain. A dynamic model can help stakeholders better understand the sustainability risks of the coffee supply chain and investigate different factors which may affect those risks. The model can be used as a tool to help make suitable decisions to mitigate the impacts of the sustainability risks. It is worth mentioning that there are many criteria related to the sustainability risks and these need to be properly considered for a reasonable and logical decision to be made.

2.1. Research Method

This research started by extracting sustainability risk factors via respondents of coffee industry players in the UK and Indonesia. These factors were grouped into five main categories: (1) risks that affect the economic, social, and environmental sustainability; (2) risks that affect the livelihood of people; (3) risks that affect the price of coffee; (4) risks that affect the potential future growth of the industry; and (5) other sustainability risk factors. These factors were validated via a literature review. A cause and effect analysis was then performed by mapping one risk factor against another.

The two SD models were initially built, embodying two points of view: the farmers' and exporters'; later on, these were combined into an integrated model ensuring that all factors and relationships are investigating in a dynamic environment. Then, adhering to the cause and effect relationship, stocks, parameters, variables, and flows were added into the model, and all the relationships amongst factors were drawn before incorporating mathematical equations to quantify the model output. Some experiments were performed according to the what-if scenarios, representing potential future situations in the supply chain. Deciding the most preferred scenario would typically need to consider more than one criterion. For this reason, we applied a multiple-criteria decision making approach using the Technique for Order Preferences by Similarity to Ideal Solution (TOPSIS) to select the preferred scenario.

The main steps of the study to build the dynamic model are illustrated in Figure 2. The model acts as a tool where different multiple criteria can be considered in order to produce suitable decisions pertaining to the sustainability risks of the Indonesia–UK coffee supply chain.

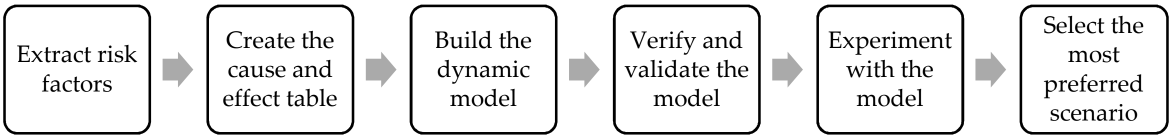

Figure 2. The main steps in the study.

2.2. Model Components

Stocks, variables, parameters, and flows are the main components of the SD model. Current levels of variables in each time step are shown in the stocks while their level changes according to the flow. This component makes it possible to see the whole model behaviour in different time periods. In this research, five stocks were investigated: uncollected coffee, collected coffee, domestic coffee usage, UK exported coffee, and other countries' exported coffee. The first stock shows the uncollected, unharvested, or not grown coffee on farms (in kg) due to, for instance climate change, agriculture productivity, and labor issues. Total collected coffee is measured in the second stock and other remaining stocks determine the usage of coffee as domestic usage or exported coffee to the UK or other countries. The following processes are undertaken for collecting coffee: processing of cherries to bean, removing the parchment layer, polishing, grading and finally sorting. It should be noted that the coffee is sorted in the country to which it is exported.

The other components of the SD model are variables that are not directly under the control of a decision maker but their values will change over time as a consequence of the values of model parameters determined by the decision makers. A total of 10 variables were considered in this research: change in coffee price, agriculture productivity, labor issues, labor supply, change in consumption pattern, land use, timeliness of supply, quality of coffee, climate change, and total exported coffee.

Decision maker's preferences can be entered into the model through the model parameters. Parameters can affect stocks, variables, or flows. A total of 14 parameters were considered in the SD model: external price factor, potential area, area increasing rate, trade policy of Indonesia, trade policy of UK, coffee per area, external factor climate change, exchange rate, transportation disruptions, unavailability of facilities, compliance with regulations, UK market demand, Other Countries (OC) market demand, and domestic market demand.

The rate of change in a stock is determined by a flow. The four flows were defined in the aggregated dynamic model: flow for the collected coffee, flow for coffee domestic usage, flow for other countries' exported coffee, and flow for UK exported coffee.

2.3. Cause and Effect Relationship between Factors

Before modeling a dynamic system, we need to understand the cause and effect relationships between all components of the model, so we extracted all factors among components (Stocks, Variables, Parameters, and Flows) from the fieldwork as well as academic papers and industry reports; the cause and effect for pairs of factors were realised and mapped in a cause and effect table (Table 3). Contents of the cause and effect map were considered with all gathered information from the supply chain players and its consistency was confirmed. Moreover, its contents were checked with the findings from the literature review. The extracted table is the basis for developing the SD model in this study. Table 3 shows the cause and effect mapping, detailing the perceived strength of the relationship amongst the factors. The relationship was validated using the data gathered from the previous steps. The rows indicated the causes and the columns showed the effects.

Table 3. Cause and effect table for the Indonesia–UK coffee supply chain.

		Parameters and Variables															**Stocks**					**Flows**				
		Price	**Quality**	**Climate**	**Productivity**	**UK TP**	**Indonesia TP**	**Livelihood**	**Disruptions**	**Consumption**	**Supply**	**Transportation**	**Exchange**	**Land Use**	**Labour**	**Regulations**	**Uncollected**	**Collected**	**Domestic**	**OC Exported**	**UK Exported**	**Collected Flow**	**Uncollected Flow**	**Domestic Flow**	**UK Export**	**OC Export**
Parameters and Variables	Price		H		M			H		H				L								H				
	Quality	H					L			H				L												
	Climate	M	L		M						L											H	M			
	Productivity		M								L			L								H				
	UK Trade Policy			L			L						L			L									M	
	Indonesia Trade Policy					L				L	L		L												M	
	Livelihood	L	L		M						L				L							H				
	Facilities disruptions									M	H	L													H	H
	Consumption	L		L																				M	M	M
	Consistency of Supply									L															M	M
	Transportation										M															
	Exchange	L											L												M	
	Land Use		L	H	L											L										
	Labour		L		H			M			L					M						H				
	Regulations	L	M	H	L			L			L			L	H							M	M			
Stocks	Uncollected																									
	Collected																									
	Domestic	M												H								H				
	OC Exported	M												H								H				
	UK Exported	M												H								H				

L: Low effect, M: Medium effect, H: High effect.

The strengths of the relationship in the cause and effect in Table 3 were indicated in four different levels: no effect, low, medium, and high effects. In total, there are more than 80 relationships among the factors. Though in theory, including all of relationships in the model will increase the model accuracy, however, it will also make the analysis more complex. Consequently, in order to simplify the model analysis but at the same time to maintain a sufficient level of accuracy, only medium and high effects were considered.

2.4. System Dynamics Model

Having finalized the cause and effect table, SD models were built in three stages. First, a model was constructed considering the Farmers' view, so only factors related to the farmers were included in this model. Then a model representing the Exporters' view was built to consider all factors related to the coffee export. Finally, the two models were integrated allowing the scope to be extended from the farmers' side to the exporters' side. Each model will be explained in detail in the following sections.

2.4.1. Farmers' View Model

The first model (Farmers' view) was built in two steps. In the first step, an initial model was constructed. It contains two stocks (potential collectable coffee and collected coffee), five dynamic variables (labor supply, labor issues, agriculture productivity, potential collectable coffee, and price of coffee change) and five parameters (coffee per area, compliance with regulations, climate change, external price factor, Indonesian coffee area). Then the relationships between the model variables and parameters were constructed in the form of a causal loop diagram (CLD), adhering to the cause and effect table. Equations between the factors were determined, too. The initial Farmers' view model is shown in Figure 3.

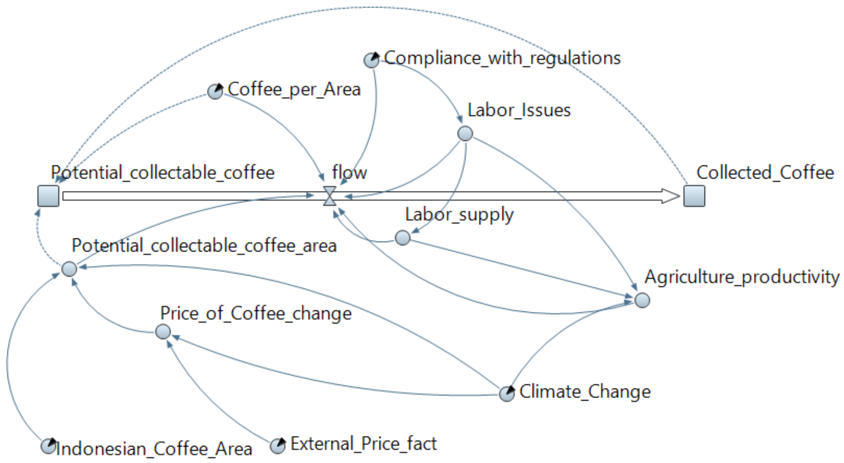

Figure 3. Farmers' view SD model.

In the second step, the Farmers' model was modified by adding two stocks (collected coffee and uncollected coffee). Accordingly, some factors were modified in the new model. The revised model for farmers' view is depicted in Figure 4.

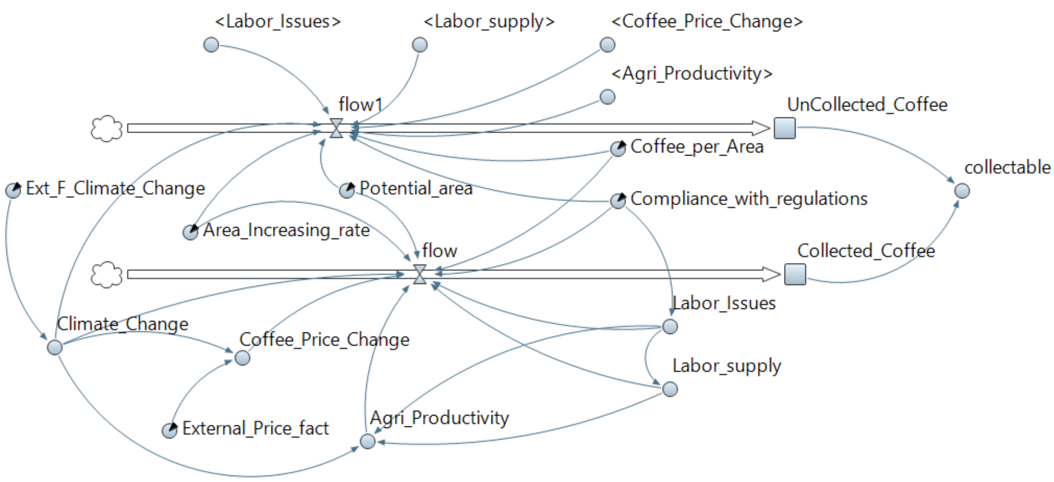

Figure 4. Revised Farmer' view SD model.

2.4.2. Exporters' View Model

After finalizing the Farmers' view model, the Exporters' view model and all related factors were considered. In this model, it was decided that collected coffee, UK exported coffee, UK exported roasted coffee and processed coffee should be included as the relevant stocks. Moreover, unavailability of facilities, timeliness of supply, transportation risks, quality of coffee, exchange rate, trade policy of UK and Indonesia, and price of coffee are the dynamic variables. The exporters' view model is shown in Figure 5.

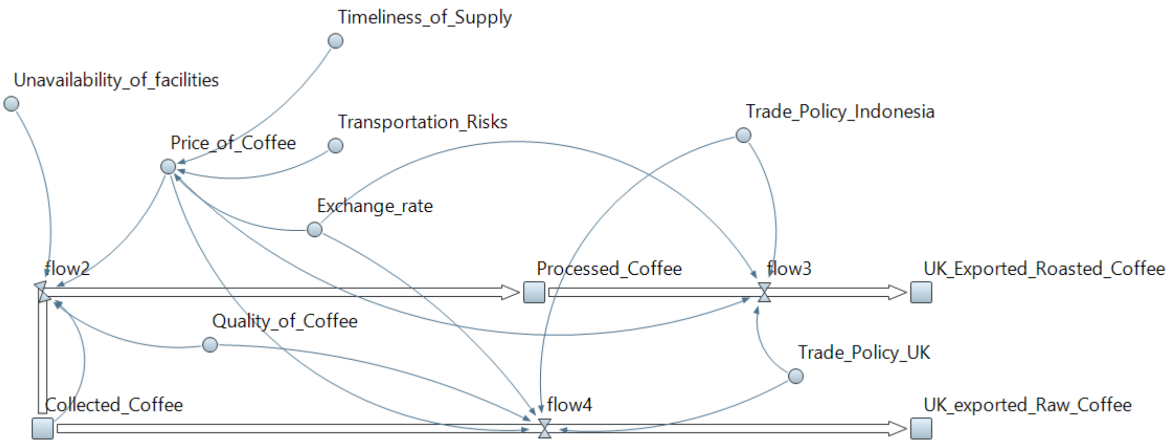

Figure 5. Exporters' view SD model.

2.4.3. Integrated Model

In this stage, and after ensuring that the extracted models of the farmers' view and exporters' view were complete and valid, the integrated model was constructed. The integrated model incorporated both farmers' and exporters' view models with some modifications, after the project team had considered all of them, as well as including the interview data with the Indonesian coffee supply chain stakeholders. In the integrated view model, uncollected coffee, collected coffee, UK exported raw coffee, other countries' exported coffee, and domestic usage are considered as stocks. There are 10 dynamic variables in this model: climate change, land use, coffee price change, agriculture productivity, labor issues, change of consumption pattern, quality of coffee, labor supply, timeliness of supply, and total exported coffee.

Finally, external factors on climate change, area increasing rate, potential area, coffee per area, UK market demand, other countries' market demand, unavailability of facilities, domestic market demand, exchange rate, compliance with regulations, UK trade policy, and Indonesia's trade policy are considered as model parameters. It should be noted that the integrated view model was considered after a discussion following the interviews as well as an in-depth analysis during the model building, amongst the project team members. The integrated view model built by combining the farmers' and exporters' views is shown in Figure 6.

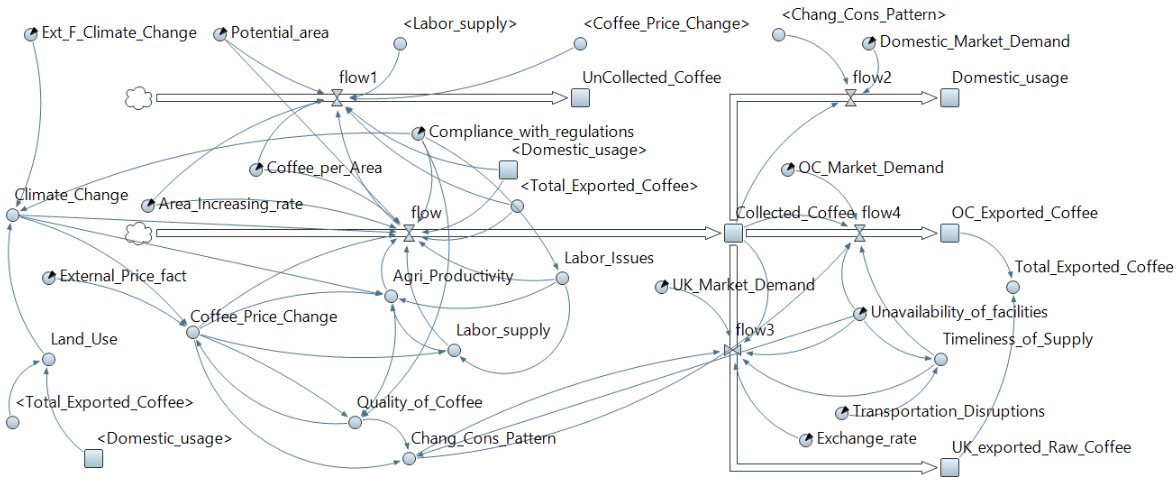

Figure 6. Integrated SD model for the Indonesia–UK coffee sustainable supply chain.

3. Results

In this section, we focus on the development of the SD models by looking into the model parameters, inputs, and outputs. These are followed by the verification and validation of the models, before running the experiments. The experimental results under different scenarios are also reported in this section.

3.1. Model Parameters, Inputs, and Outputs

As the model is considered over a monthly period, the model's unit time was also set to month. In the model developed, an initial value needs to be assigned for the model parameters with a range of minimum and maximum initial (assignable) value. The values for the integrated model parameters are listed in Table 4; reported values in this table were retrieved from current statistics available from the International Coffee Organisation (ICO) and other sources [2]. Furthermore, the models also considered several of assumptions, for instance: average rate of coffee domestic usage and average rate of coffee export are assumed to be 0.6 and 0.4, respectively, based on a recent report [41].

Table 4. Range and initial values of parameters in the integrated dynamic model.

Parameter	Min	Max	Initial Value
External Price Factor	0	-	0.00583
Area Increasing Rate	0	1	0.00026
Potential Area	0	-	1,243,518 (ha)
Trade Policy of Indonesia	1	2	1
Trade Policy of UK	1	2	1
Coffee per area	0	-	63.06 (kg/ha in one month)
External Factor Climate Change	1	2	1.00001
Exchange Rate	1	2	1.5
Transportation Disruptions	1	2	1
Unavailability of Facilities	1	2	1
Compliance with Regulations	1	2	1
UK Market Demand (%)	0	1	0.05
OC Market Demand (%)	0	1	0.95
Domestic Market Demand (%)	0	1	0.6
Agriculture productivity	0	1	0.95

Input and output data specifications of the models are listed in Table 5. The dynamics of the models can be assessed by changing the values of input data and by observing the resultant outputs. Model inputs can be adjusted by using sliders; for each input data (parameters) change, the model is run and the model outputs can be plotted and analyzed, making it easier for the decision makers to make sense of the model. Figure 7 illustrates the final model view of the extracted integrated model for experimentation. Boxes at the bottom of the SD model show various input parameters that can be adjusted during the experimentation.

Table 5. Inputs and outputs of the integrated dynamic model.

Inputs	Outputs
Coffee per area	Total exported coffee
Compliance with regulations	Exported coffee to the UK
Potential area	Exported coffee to other countries
Area increasing rate	
External price factor	
External Climate change factor	
Trade policy Indonesia	
Trade policy UK	
Transportation disruption	
Exchange rate	
UK market demand	
Domestic market demand	
OC market demand	
Unavailability of facilities	

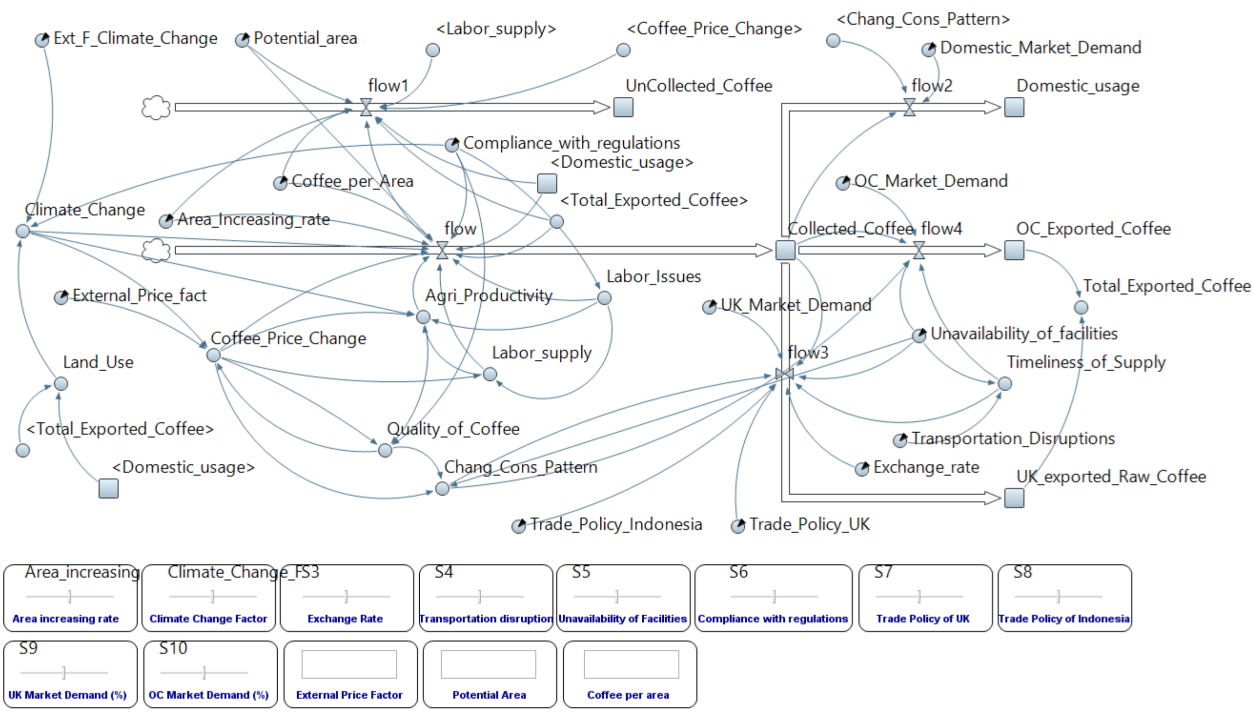

Figure 7. Integrated SD model showing the various input parameters using sliders.

The relationships between the model components have been defined based on the available data extracted from the field study (surveys and interviews) and project team discussion, and they appear as equations in the model. All of the equations are reported in Appendix A.

3.2. *Model Verification and Validation*

The integrated model can be used as a tool for any experimentation to see how the model outputs will change over time as a consequence of some actions, or as a result of a policy being imposed. The model needs verification and validation over several stages. The first stage ensures the consistency between sustainable supply chain risk factors extracted from the interviews and the literature, with the selected parameters, flows, and variables in the integrated dynamic model. Checking the cause and effect table was the second stage, which was completed by a walk-through method and in-depth discussion with the project team. Here, we ensured that the elements in the cause and effect table are reasonably consistent with the results of previous studies. Then, the model components, links between the model elements and its equations were double-checked for consistency with the extracted cause and effect matrix. The different parts of the model were checked separately to ensure that the expected performance was achieved. A sensitivity analysis in different parts of the model was then performed. In this analysis stage, we varied the values of some parameters in the model and observed the expected values of the dynamic variables. As an example, we considered the effect of changing the "Area increasing rate" on the "Amount of exported coffee". As shown in Figure 8, when we increased the value of "Area increasing rate" parameter in the model (using the sliders), we also saw an increasing slope of exported coffee to other countries.

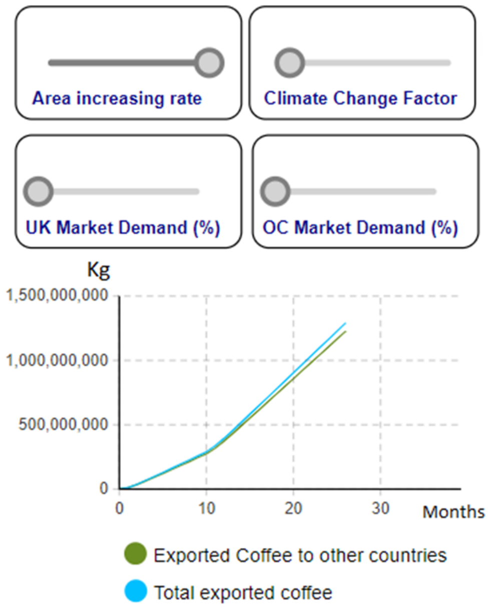

Figure 8. Sensitivity analysis of "Area increasing rate" parameter on the exported coffee.

As another check, the effect of "Climate Change Factor" was investigated on the exported coffee. As illustrated in Figure 9, it is observed that the climate change affected the agriculture performance which led to a reduction in the exported coffee, and this confirmed the logical behaviour of the dynamic model.

Furthermore, we investigated the effect of transportation disruption on the coffee supply chain. We observed that by increasing the transportation disruption parameter in the model, the total exported coffee to the UK and other countries dropped. This is because of the non-timely delivery of coffee which also affects the decision making of importers in the coffee supply chain. We ran an experiment in the dynamic model, illustrated in Figure 10, which reconfirmed the logical behaviour of the dynamic model. The above-mentioned analyses have verified the appropriateness of the integrated dynamic model.

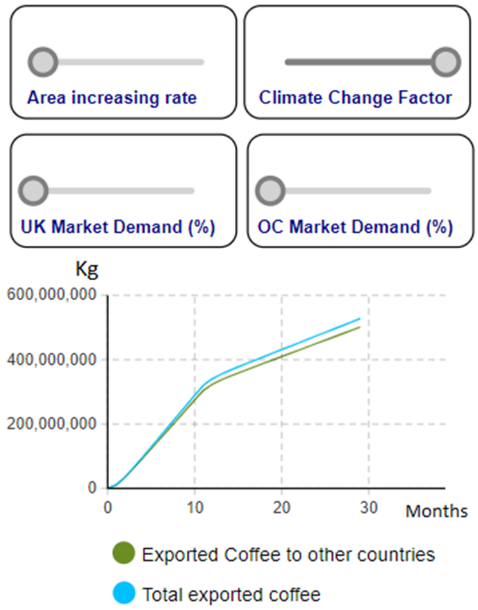

Figure 9. Sensitivity analysis of "Climate Change Factor" parameter on the exported coffee.

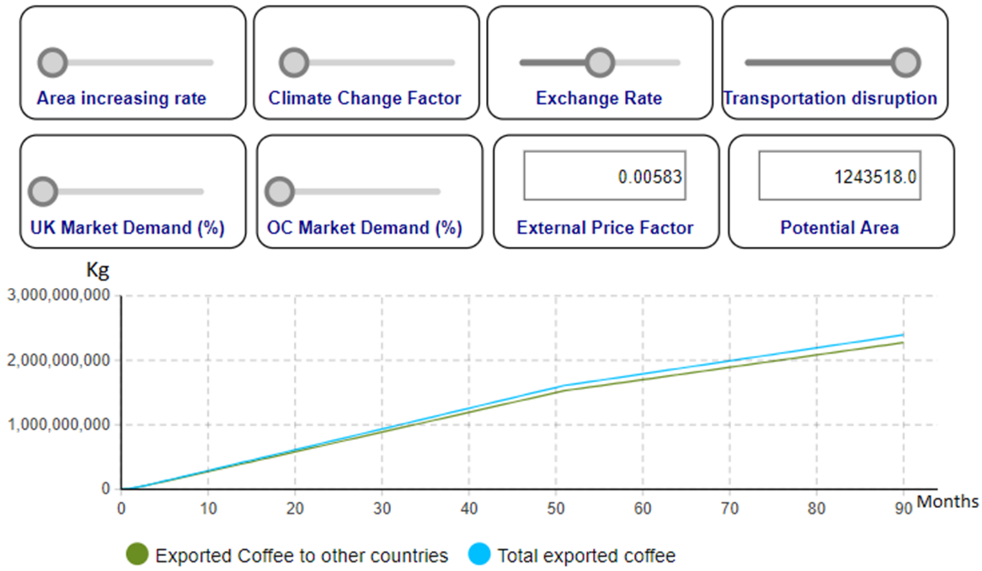

Figure 10. Effect of "Transportation disruption" on exported coffee.

Although the model was verified according to the above-mentioned experiments and analyses, it still needed to be validated. During the validation, the model performance was evaluated as a whole and a unified system. To do that, we set the values of all parameters on their current status and ran the model for the period of one year. Then total collected coffee and total exported coffee were considered. According to the previous published reports, we expected to observe the proportion of 40% for exported coffee. After running the model for one year, the model shows that the total exported coffee will reach 376,156,447 kg, while the total collected coffee in that period is 940,396,761 kg. The calculated exported coffee proportion will therefore be (376,156,447/940,396,761) = 0.399, which is almost our expected 40% value for a year.

For another validation check, we evaluated the total Indonesian coffee generated from the dynamic model and compared it with the expected value based on the previous reports. From the reports, we know that there are 1,243,518 ha of total coffee plantation area in Indonesia. Whilst it has been reported that 765 kg coffee is produced per ha in a year (Coffee per area = 63.06 kg/ha in a month), we could expect the total collected coffee to be 951,291,270 kg coffee in a year. After running the integrated dynamic model for a period of one year, the values of Exported Coffee to other countries, UK Exported Coffee, Total Exported Coffee, Domestic Usage and Total Coffee are generated by the model (see Table 6).

Table 6. Values for stocks and variables after the first year.

Stock/Variable	Value at the Period of 12 Months (Tons)
Exported coffee to other countries	357,349
UK exported coffee	18,808
Total exported coffee	376,156
Domestic usage	564,240
Total coffee	940,397

The dynamic model status after the one-year simulated run time is depicted in Figure 11. It was observed that the total coffee = Domestic usage + Total exported coffee, which is equal to 940,396,761 kg. After running the model for one year, it can be confirmed that the value for the total collected coffee is very close to our expected value; therefore, it confirms the validity of the model.

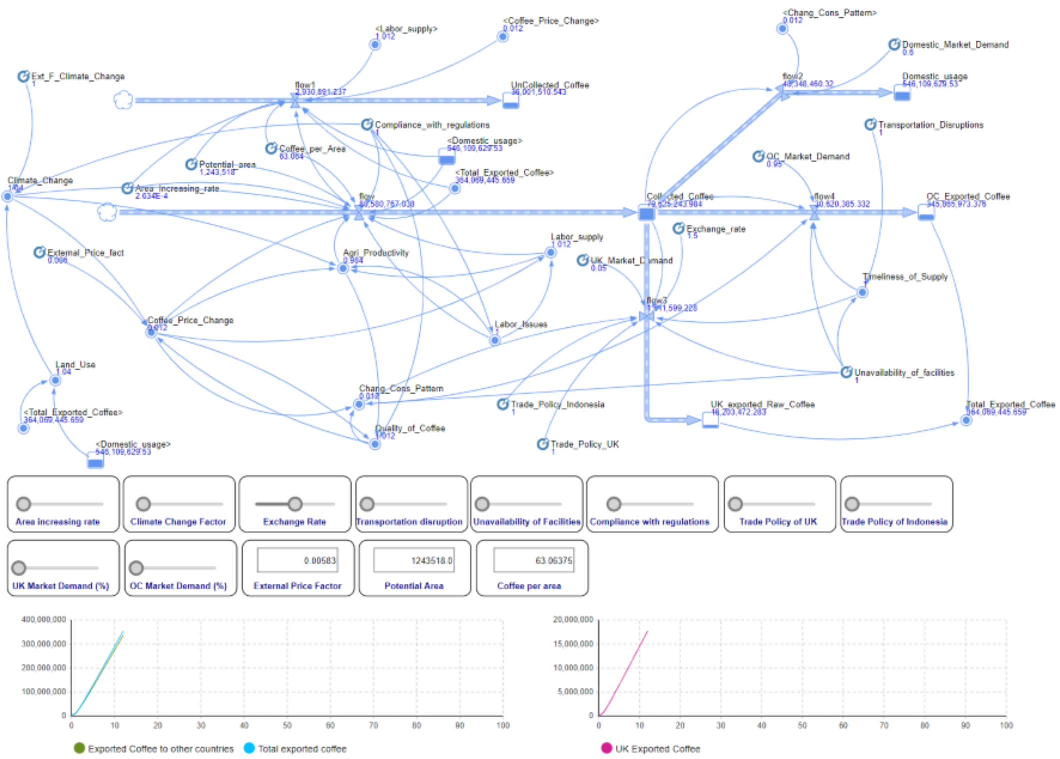

Figure 11. The model performance after a period of 12 months.

3.3. What-If Scenarios

After confirming the extracted model in terms of validation and verification, some scenarios were envisaged according to the team concerns regarding the interviews with Indonesian coffee supply chain stakeholders in two interview stages of the project. The following scenarios were extracted or envisaged: Certification and Traceability (Scenario 1), Demand increase from UK Market (Scenario 2), Productivity change (Scenario 3), Pandemic situation (Scenario 4), and Sustainability actions by the government (Scenario 5). Extracted scenarios are based on the current situation or predicted and possible ones and we investigated each scenario; however, the extracted dynamic model will give the possibility of considering any other possible scenarios to be investigated by decision makers to extract the best decision in a multiple criteria decision-making environment.

In the next step, each scenario was considered with the project team to determine the impact of each scenario on the model parameters or inputs. The discussion was performed according to the results of interviews in previous stages as well as project group members' expertise in the coffee supply chain. The implications of each scenario on the model parameters have been summarised in Table 7. As an example, it shows that implementation of certification and traceability (Scenarios 1), will have a positive high impact on the "compliance with regulations".

Table 7. Implications of considered scenarios on the dynamic model parameters.

	Scenario				
	1	**2**	**3**	**4**	**5**
External factor climate change					-
Area increasing rate					
Potential area					
Coffee per area			+ +		
Compliance with regulations	+ +				+ +
Transportation disruptions				+ +	
Exchange rate					
Trade policy UK					
Trade policy Indonesia					
External price factor	+ +				
UK market demand		+ +		- -	
Domestic market demand				- -	
Other countries market demand				- -	
Unavailability of facilities				+ +	

The "+" and "-" signs show the positive and negative impacts, respectively; the quantity indicates the strength of the impact.

By using the impact of each scenario, the model parameters are changed to simulate each scenario and finally the model will be run to extract the values of output variables. This scenario analysis will help decision makers to see the impacts of their decisions. Because of the simulation nature of this analysis, it will impose negligible costs compared to the changes to a system in a real environment. Additionally, it gives us the possibility to measure the value of various dynamic variables instead of facing single criterion decision making which will lead to more effective and more reliable decision making. By considering the above-mentioned scenarios, it is possible to investigate what might happen to the Indonesian coffee supply chain under the influence of each policy. Then we run the dynamic model under each scenario with two time periods, i.e., one and ten years. This gave us an idea of the policy effectiveness in a short- and medium-term run. The results of the model variables under each scenario with the simulated short- and medium-term runs are reported in Table 8. More explanation is provided for each scenario in the following subsections.

3.3.1. Scenario 1: Certification and Traceability

Improving the certification of coffee in Indonesia, which is accompanied by better traceability of the product, is one route towards furthering the sustainability of the supply chain, and mitigating potential risks. By implementing this scenario, the value for the 'compliance with regulations' will be set as 'high' and will increase the coffee price (as the price of coffee is predicted to rise with increased certification and traceability). After running the model by changing its corresponding parameters' values according to Table 8, it can be observed that the total exported coffee to the UK has been slightly decreased.

Table 8. Results of running the dynamic model under different scenario.

		Volume (Tonnes)					
		Current Situation	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**
1-Year Simulated Run Time	Exported coffee to UK	18,808	12,565	262,711	22,736	15,396	12,589
	Exported coffee to other countries	357,349	238,744	267,404	431,990	292,533	239,195
	Total exported coffee	376,156	251,310	530,115	454,726	307,929	251,784
	Domestic usage	564,240	376,968	422,221	682,096	638,560	377,679
10-Year Simulated Run Time	Exported coffee to UK	194,191	154,940	3,560,366	230,171	156,349	109,690
	Exported coffee to other countries	3,689,625	2,943,856	2,359,631	4,373,249	2,970,633	2,084,116
	Total exported coffee	3,883,816	3,098,796	5,919,997	4,603,420	3,126,982	2,193,806
	Domestic usage	5,825,782	4,648,240	3,725,770	6,905,199	6,579,279	3,290,742

3.3.2. Scenario 2: Demand Increase from the UK Market

This scenario predicts the impact of an increase in UK coffee demand from Indonesia. According to the findings of the research in previous stages, it was concluded that it will not affect the values of other parameters in the model. However, it was expected that the total exported coffee to the UK will be increased. The results confirm that under this scenario, the total exported coffee to the UK at 10-year simulated run time will be increased with a decrease in the domestic coffee usage in Indonesia.

3.3.3. Scenario 3: Productivity Change

This scenario anticipates the impact of an increase in agricultural productivity. This is tested by setting the parameter of coffee per area as 'high'. The results of this scenario confirm that all the output variables will be increased as the productivity increases. The reason for this is that the total collected coffee will increase and because other factors do not change, the total exported coffee to the UK or other countries will increase significantly.

3.3.4. Scenario 4: Pandemic Situation

This scenario evaluates the impacts of the COVID-19 pandemic on the Indonesia–UK coffee supply chain. In this scenario, it was hypothesized that transportation disruptions might happen during the pandemic. Moreover, unavailability of resources and processing facilities was another anticipated change during the pandemic, as well as decreasing demand from UK and other countries. After running the model under this pandemic scenario, the results show that there will be a decrease in the total exported coffee to the UK and other countries, as illustrated in Figure 12.

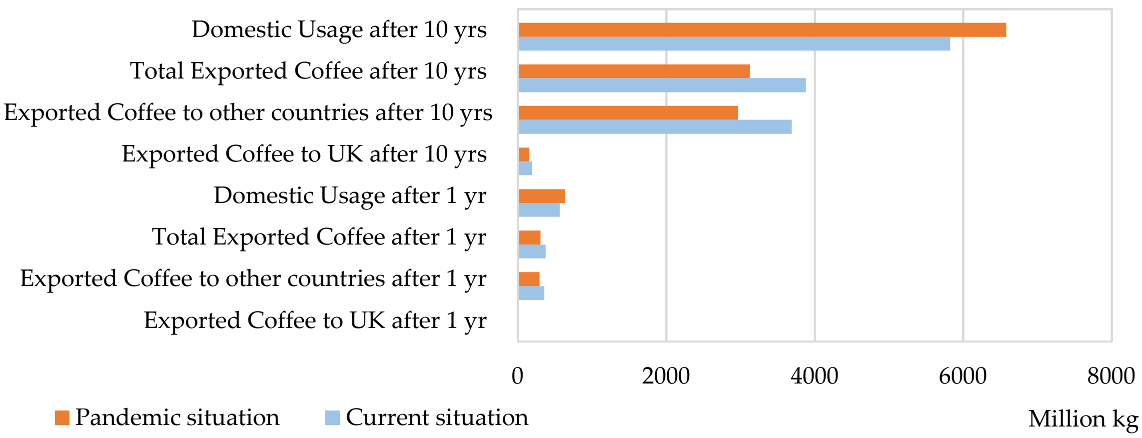

Figure 12. Stock values in the dynamic model comparison under current and pandemic situations.

3.3.5. Scenario 5: Sustainability Actions by Government

This scenario predicts the consequences when the UK and Indonesian governments embrace further sustainability actions, in particular when the local level governance in Indonesia imposes further sustainable policies on the growers, in the harvesting and processing of coffee. To evaluate this scenario, the values of some model parameters were modified. A higher value is used for the compliance with regulations, while the climate change parameter in the model is decreased. After running the model, the total exported coffee decreases during a 10-year simulated run time. The results indicate that the scenario itself is not sufficient to achieve a sustainable supply chain, so additional strategies may be necessary.

As mentioned before, the model can act as a framework to support multiple criteria decision making. Different policies can be evaluated by measuring various dynamic variables. In this study, the aforementioned scenarios, as well as the current state were then evaluated using a multiple criteria decision-making approach, with three dynamic variables in both short- and medium-term periods. The structure of the decision-making approach under a multiple criteria scheme is illustrated in Figure 13.

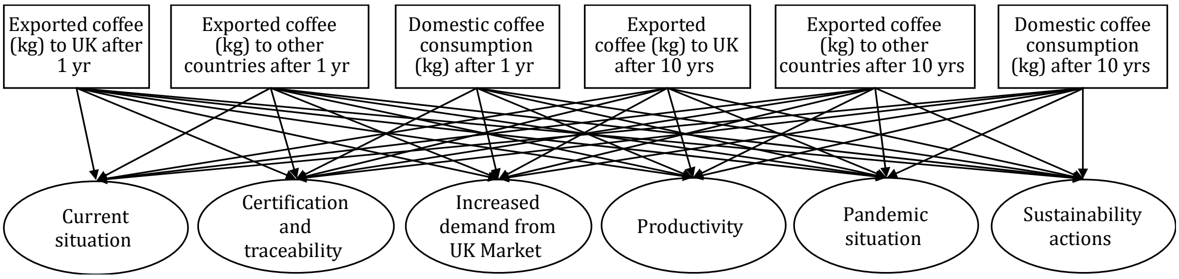

Figure 13. An example of multiple criteria decision making for the coffee supply chain risks.

In this example, we have six selected criteria based on the calculated dynamic variables in two different simulated run times (1 year and 10 years), and we are also faced with more than one criterion for the decision. We therefore adopted the TOPSIS method to evaluate and rank the usefulness of the scenarios. In this case, we assumed a weight vector of (0.2, 0.1, 0.05, 0.3, 0.2, 0.15) for the decision criteria. The weighted normalized matrix is shown in Table 9. After calculating the distance of each scenario from the positive and negative ideal solutions, the results are integrated. The scenarios are then evaluated and ordered according to the aggregated score (see Table 10). It can be seen that Scenario 3, "Productivity", is the most preferred scenario.

Table 9. Weighted normalized table for the multiple criteria decision making using the coffee supply chain dynamic model.

	Exported Coffee to UK	Exported Coffee to Other Countries	Domestic Usage	Exported Coffee to UK	Exported Coffee to Other Countries	Domestic Usage
Weight	**0.2**	**0.1**	**0.05**	**0.3**	**0.2**	**0.15**
Scenario	**1-Year Simulated Run Time**			**10-Year Simulated Run Time**		
Current Situation	0.071	0.467	0.439	0.054	0.476	0.445
1	0.047	0.312	0.293	0.043	0.380	0.355
2	0.990	0.349	0.328	0.994	0.304	0.285
3	0.086	0.565	0.530	0.064	0.564	0.528
4	0.058	0.382	0.496	0.044	0.383	0.503
5	0.047	0.313	0.294	0.031	0.269	0.251

Table 10. Final results of multiple criteria decision making for the coffee supply chain.

Scenario	Distance to Negative Ideal Solution	Distance to Positive Ideal Solution	Closeness Criteria (CC)
Current situation	0.054	0.337	0.138
1	0.027	0.346	0.073
2	0.345	0.068	0.836
3	0.078	0.332	0.191
4	0.046	0.343	0.118
5	0.000	0.354	0.000

4. Discussion

Although in every supply chain, we will face the three pillars of sustainability, i.e., economic, environmental, and social, depending on the type of supply chain, the role of each pillar might be changed. In this study, the distribution of sustainable coffee supply chain risks among all the above-mentioned pillars are 39, 18, and 43%, respectively. This shows that for the coffee supply chain, there are many social aspects which need to be considered carefully. It might be because of the major role of the people who are involved during the different steps of the coffee supply chain from planting, to harvesting, to processing. This also means that this pillar needs to be sufficiently considered for any decision making in the supply chain to ensure its sustainability.

According to the cause and effect analysis, we can conclude that price, land use, supply, productivity, and consumption are the factors which may be influenced more by other factors in the coffee supply chain. It shows that the decisions and any actions which reduce the effects of other factors on the coffee supply chain will be more effective to make the supply chain sustainable. However, because of the dynamic nature of events around us, a dynamic model will help us analyze the effect of each factor.

The what-if scenario analysis is one of the analysis methods that provides a decision maker with the idea of considering the dynamic effects and finally to make an appropriate decision. A total of five scenarios have been considered in this study. The scenarios to some extent are related to the main factors which were extracted from the cause and effect analysis. The usefulness of the dynamic models is that many scenarios can be considered and there is no limitation on using the dynamic model to see what will happen if a similar strategy is used in the future. As the amount of collected coffee and exported coffee (to the UK and other countries) are important output variables in this study, all of the scenarios were evaluated according to the output variables.

The main benefit of the dynamic model is that we can visualize the change of output or other important factors over time. It provides us with a better understanding of the model behaviour when we are faced with a set of complex factors. The other benefit of the model is the possibility of doing some experiments by changing some input factors to see how they will affect the target output variables. By combining the dynamic model with the multi-criteria decision-making approach, it is now possible to determine the most preferred simulation scenario considering more than one criterion as the target outcome.

We adopted TOPSIS because of its tendency to find a preferred scenario that is sufficiently close to the positive ideal solution and be far enough from the negative ideal solution as much as possible. According to available scenarios, increasing the agriculture productivity was found to be the most preferred scenario to achieve the sustainable coffee supply chain; not only does it increase the output rate, it will also consider other pillars of sustainability.

5. Conclusions

In this study, the sustainability risks of the Indonesia–UK coffee supply chain were studied. We first considered the risk factors by conducting a survey from coffee supply chain stakeholders in both UK and Indonesia. The findings, combined with the literature review, were used as a basis for the development of an SD model. SD allows the observation of the system's behaviour considering all the related factors in a dynamic environment. The input and output parameters and the equations in the model were set accordingly. The model was verified and validated in different stages using the views of experts in the coffee supply chain. The SD model is hereby used to analyze threats posed by the sustainability risks. By using SD, the way in which the coffee supply chain reacts to the disturbances caused by the sustainability risks can be observed.

The five what-if scenarios were developed, experimented and compared with the current state. The main outcome of this study confirms that the combination of the dynamic model and the multiple criteria decision-making tool is found to be effective in addressing the various issues in the coffee supply chain. The results show that, considering the multiple criteria, increasing the agriculture productivity is the most preferred scenario, among others. As a future work, we would like to enhance the SD model and use more precise input parameters, for instance, by using fuzzy values, and evaluating more scenarios.

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

Appendix A

Table A1. Equations used in the SD model.

Model Component	Equation
Flow	Coffee_per_Area * Potential_area/(0.0001 + Labor_Issues) * Labor_supply * Agri_Productivity * (1 + Area_Increasing_rate) * (2 / (Compliance_with_regulations+Climate_Change)) * (1 + Coffee_Price_Change) * (1 + 0.1 * Total_Exported_Coffee / (0.000000001 + Total_Exported_Coffee + Domestic_usage))
Flow 1	(Coffee_per_Area * Potential_area * (1 + Area_Increasing_rate) * (1 + Coffee_Price_Change)) * Labor_supply * (1 + 0.1 *Total_Exported_Coffee / (0.000000001 + Total_Exported_Coffee + Domestic_usage))−flow
Flow 2	Collected_Coffee * (1 + Chang_Cons_Pattern) * Domestic_Market_Demand
Flow 3	0.4 * Collected_Coffee * Trade_Policy_Indonesia * Trade_Policy_UK * Exchange_rate/1.5 * UK_Market_Demand * Unavailability_of_facilities * Timeliness_of_Supply * (1 + Chang_Cons_Pattern)
Flow 4	0.4 * Collected_Coffee * OC_Market_Demand * (1 + Chang_Cons_Pattern) * (2 − Unavailability_of_facilities) * Timeliness_of_Supply
Timeliness_of_Supply	1 / (0.00001 + Transportation_Disruptions * Unavailability_of_facilities)
Total_Exported_Coffee	OC_Exported_Coffee + UK_exported_Raw_Coffee
Quality_of_Coffee	1 + Compliance_with_regulations * Agri_Productivity * Coffee_Price_Change
Chang_Cons_Pattern	Quality_of_Coffee * Coffee_Price_Change / (0.00001 + Unavailability_of_facilities)
Coffee_Price_Change	External_Price_fact * (1 + (1 + (Climate_Change − 1) / 5) * Quality_of_Coffee)
Land_Use	1 + 0.1 * (Total_Exported_Coffee / (0.0000001 + Total_Exported_Coffee + Domestic_usage))
Climate_Change	Ext_F_Climate_Change / (1 + (Compliance_with_regulations − 1) / 10) * Land_Use
Agri_Productivity	1 * 1 / Labor_Issues * ((1 + Coffee_Price_Change) * Labor_supply) * (1 / Climate_Change)
Labor_supply	1 + 1 / (0.00001 + Labor_Issues) * Coffee_Price_Change
Labor_Issues	1 + (Compliance_with_regulations-1) / 2

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