Implications of Integrating Sustainability on Supply Chain Network Design Decisions

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International Transport Forum

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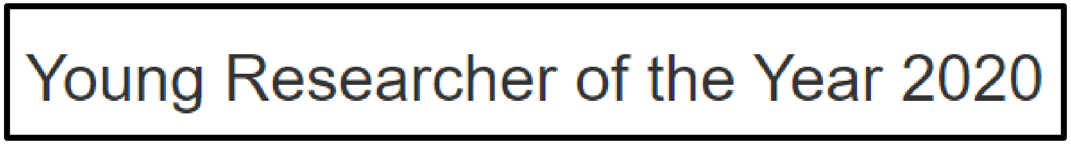
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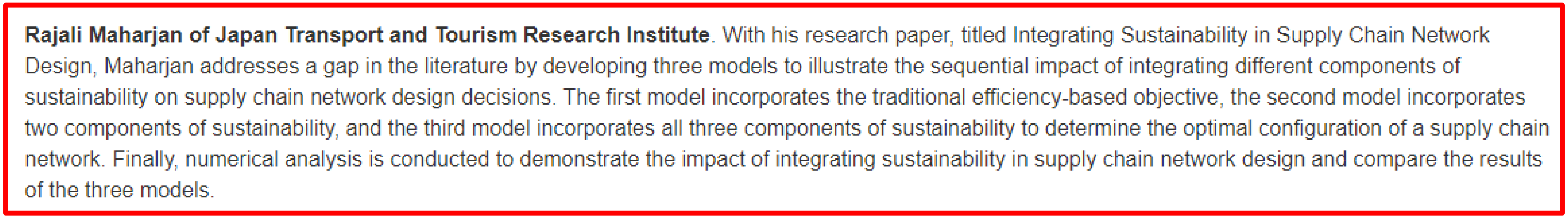
Rajali Maharjan of Japan Transport and Tourism Research Institute. With his research paper, titled Integrating Sustainability in Supply Chain Network Design, Maharjan addresses a gap in the literature by developing three models to illustrate the sequential impact of integrating different components of sustainability on supply chain network design decisions. The first model incorporates the traditional efficiency-based objective, the second model incorporates two components of sustainability, and the third model incorporates all three components of sustainability to determine the optimal configuration of a supply chain network. Finally, numerical analysis is conducted to demonstrate the impact of integrating sustainability in supply chain network design and compare the results of the three models.

Maharjan, R., Asakura, Y., Nakanishi, W. and Wang J. Y. T. (2019). Integrating sustainability in supply chain network design, *Journal of the Eastern Asia Society for Transportation Studies*, Vol. 13, pp. 975-992.

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Outline of the presentation

1. Introduction
2. Literature review
3. Problem description
4. Model formulation
5. Solution approach
6. Numerical illustration
7. Summary and conclusion
8. Limitations and future research

Introduction

Supply chain management (サプライチェーンマネジメント)

Supply chain management is a set of approaches utilized to efficiently integrate suppliers, manufacturers, facilities, stores and end users, so that merchandise is produced and distributed at the right quantities, to the right locations, and at the right time, in order to minimize systemwide costs while satisfying service level requirements.

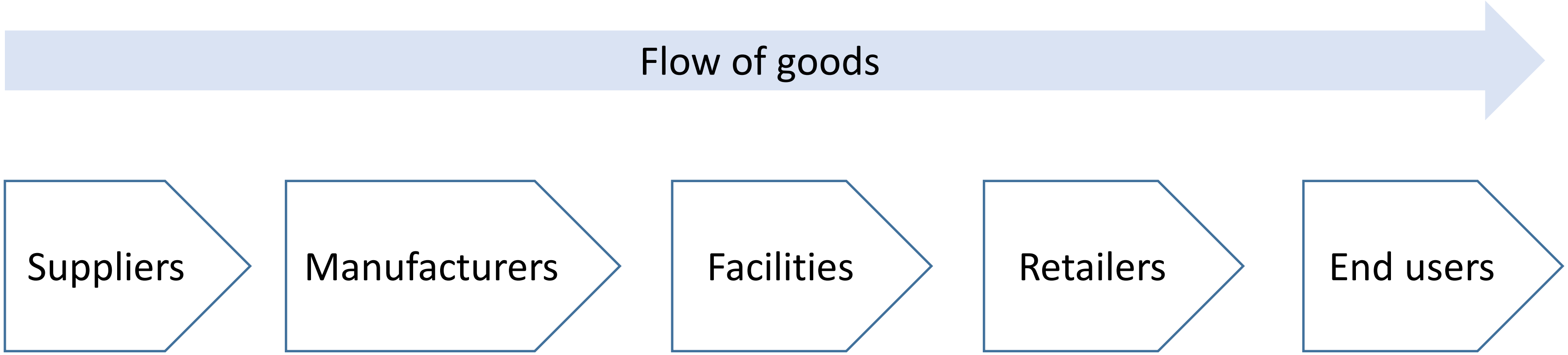
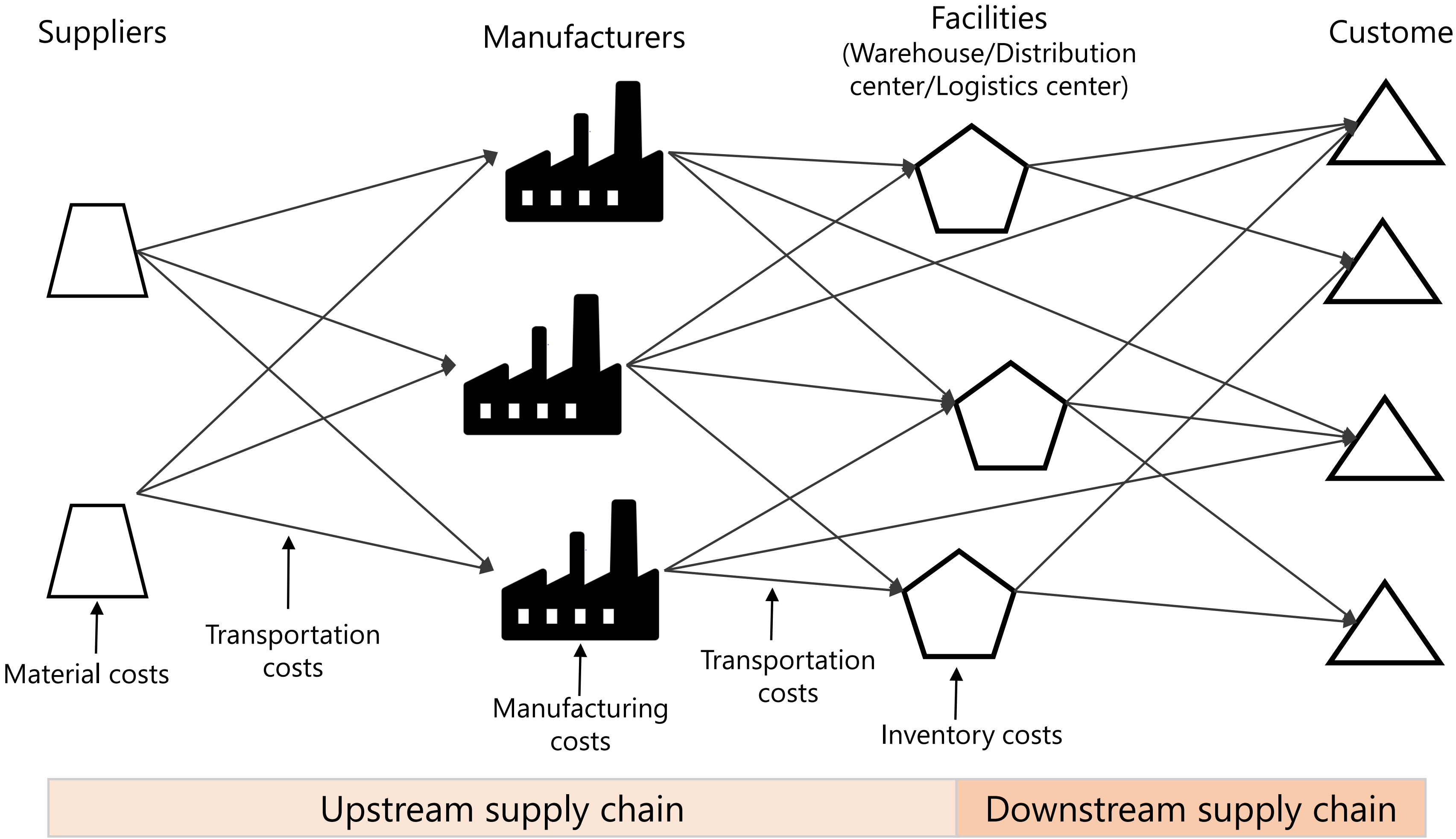


Figure 1: Supply chain management

Supply chain network

A supply chain consists of a network of suppliers, manufacturers, facilities (like warehouses, distribution centers, logistics centers) and customers.



Suppliers

Manufacturers

Facilities
(Warehouse/Distribution center/Logistics center)

Customers

Material costs

Transportation costs

Manufacturing costs

Transportation costs

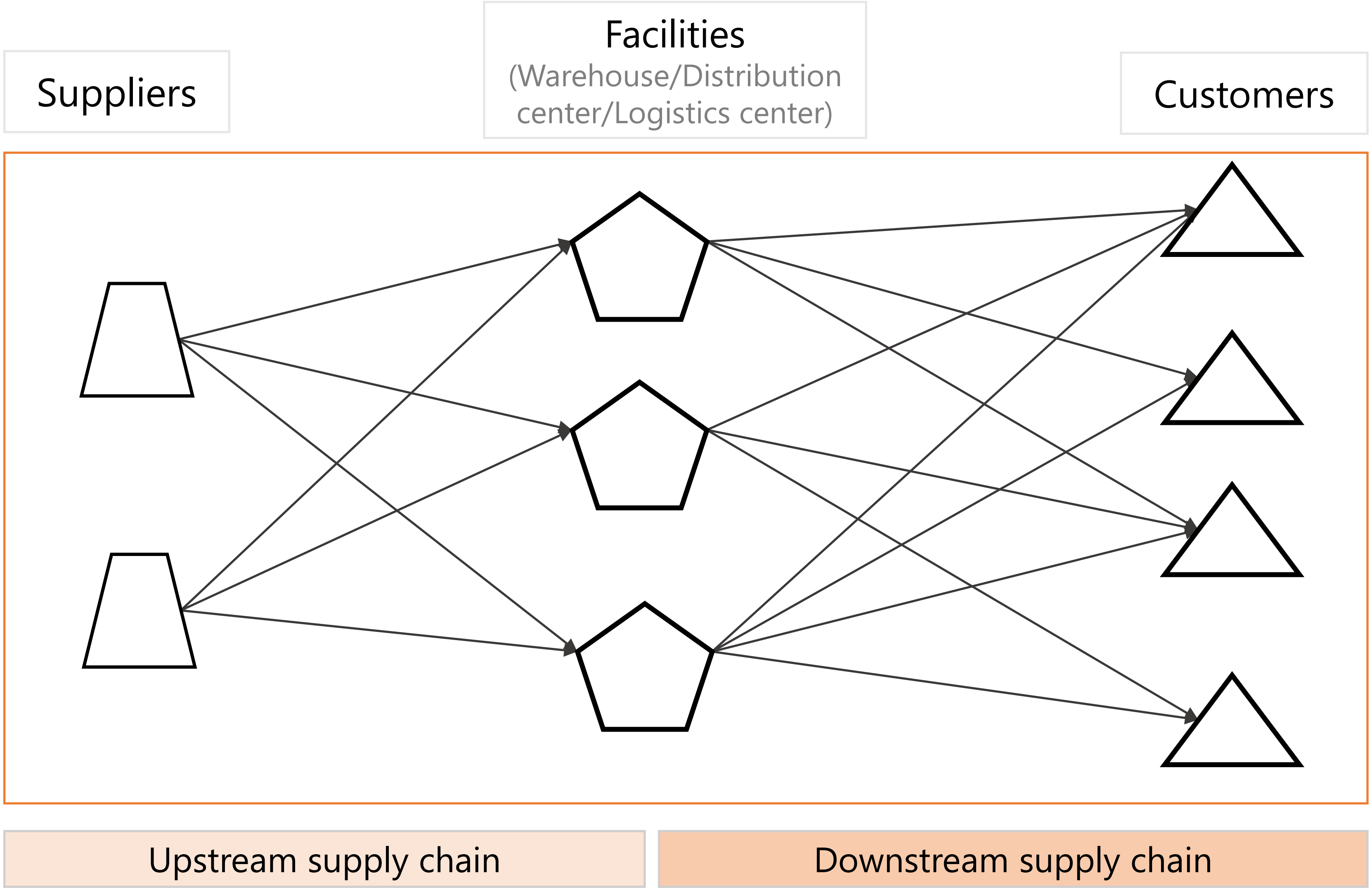
Inventory costs

Upstream supply chain

Downstream supply chain

Figure 2: Typical structure of supply chain network
(Concept derived from Simichi-Levi et al., 1999)

Supply chain network (without manufacturing center)



Suppliers

Facilities
(Warehouse/Distribution center/Logistics center)

Customers

Upstream supply chain

Downstream supply chain

Figure 3: Alternative structure of supply chain network

Types of supply chain network examples

With own manufacturing centers and facilities.

Kao Corporation

Toyota Motor Corporation

(Uses combination of own logistics capacities and/or 3PL companies)

Without own manufacturing centers and/or warehouses and/or distribution centers

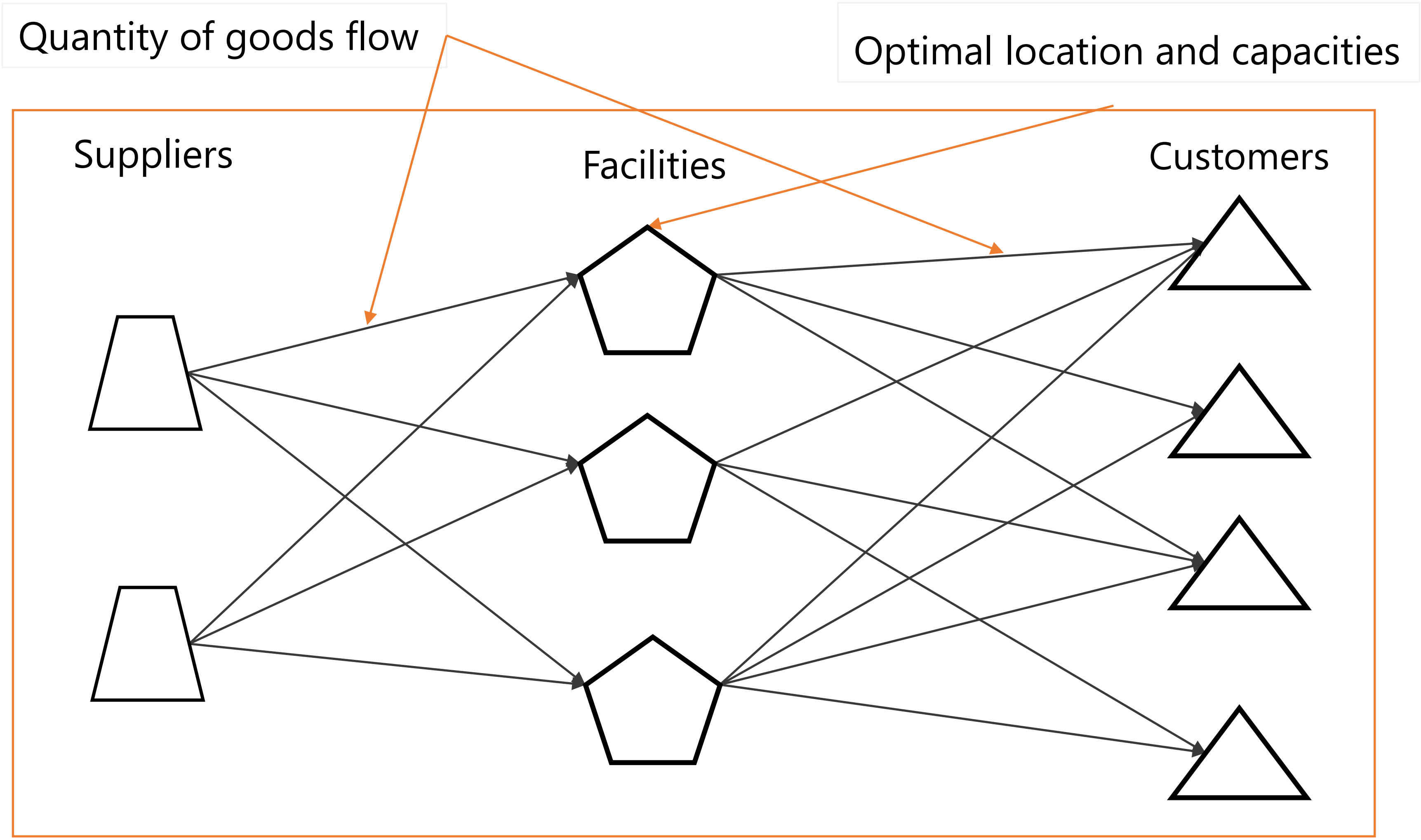
ITO Corporation

Trading company

(Uses 3PL companies)

Supply chain network design (SCND)

In general, SCND is a systematic approach to determining the best location, number, and optimal capacities of the facilities, and quantity of flow between them (Amiri, 2006).



Importance of SCND

Supply chain network design is one of the most crucial planning problems in supply chain management because

- the structure of a supply chain cannot be altered over the short term due to the time and costs associated with such activities.
- design decisions are expected to be viable enough to function well under complex and uncertain business environments for many years.

Thus, establishing a well-conceived supply chain network from the beginning is essential for facilitating sustainable development over the long term.

Sustainability in supply chain management

Sustainability entails that a system is capable of meeting the needs of the present without compromising the ability of future generations to meet their own needs (Bruntland Commission, 1987) .

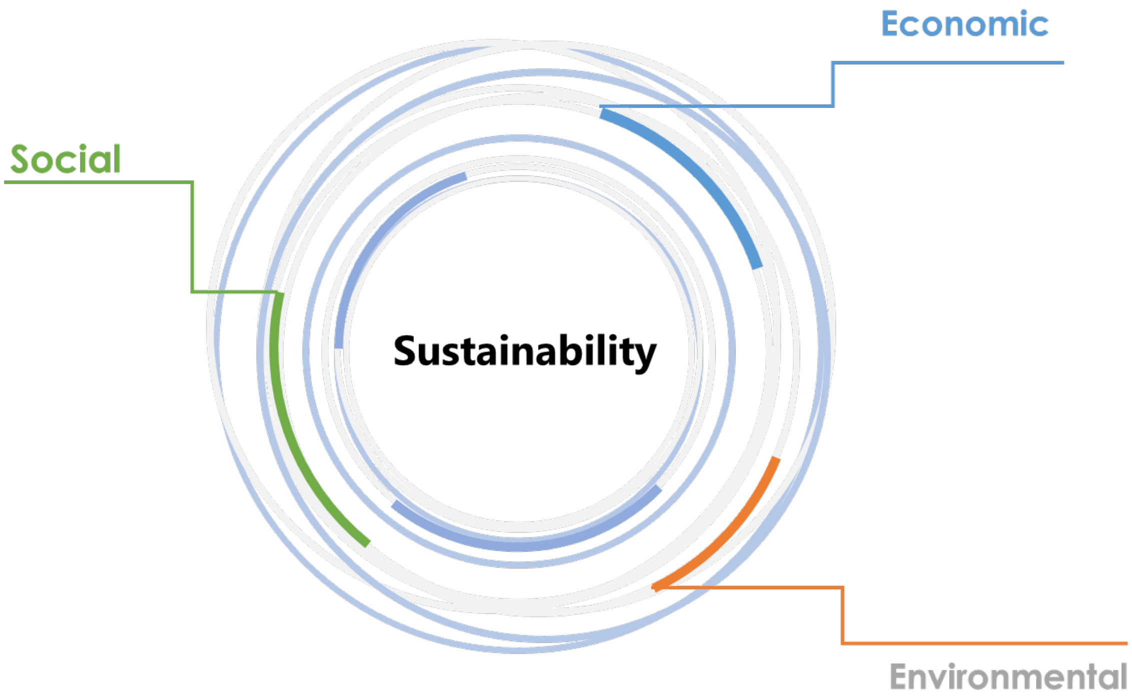


Figure 4: Components of sustainability

Sustainability of Supply Chain can be perceived as the proper management of related economic, environmental, and social impacts in constructing and maintaining effective and efficient global supply chains.

Importance of sustainability in SCND

Typically, SCND has been done in a manner that provides the required level of customer service at the lowest cost or highest profit.

In recent years, increased pressure from various stakeholders, such as customers, suppliers, regulators, competitors, local and global communities, and nongovernmental organizations, have prompted the manufacturing industry to integrate sustainability-conscious practices into their business not only at the firm level, but also for the entire supply chain (Corbett and Klassen 2006; González-Benito and González-Benito 2006).

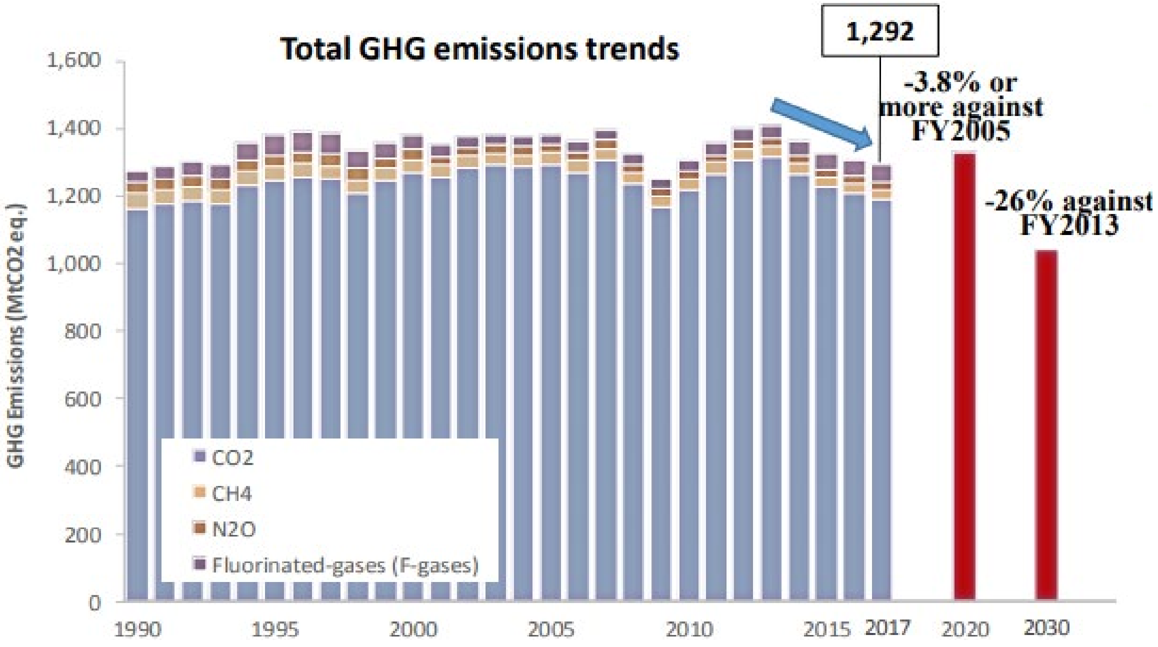
Sustainable SCND has attracted considerable attention in recent years as a means of dealing with a broad range of environmental and social issues.

Many companies with existing supply chain networks are accelerating their efforts to reorganize the traditional supply chain and follow the changes.

Practical relevance of this research

Japan's total greenhouse gas emissions in 2017 were 1,292 Mt CO_2 equivalent which ranks it **5th** in the list of highest emitters in the World.[1]

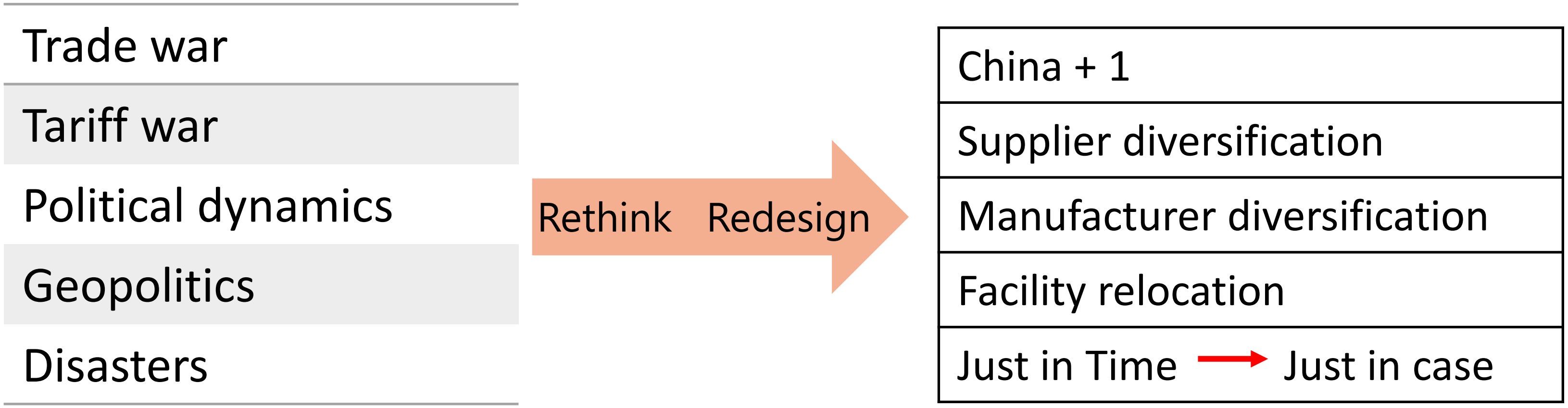
Japan's GHG emission reduction target by 2030[2]



More than three quarters of the greenhouse gas (GHG) emissions associated with many industry sectors come from their supply chains (Huang et al., 2009) which is why **SUSTAINABILITY** consideration in SCND is very important.

Source: 1. Global Carbon Project. "Global Carbon Budget" https://www.globalcarbonproject.org/carbonbudget/archive/2018/GCP_CarbonBudget_2018.pdf Page 18-19.
2. https://unfccc.int/sites/default/files/resource/Japan_MA2019_presentation.pdf Page 3.

Practical relevance of this research



- Trade war
- Tariff war
- Political dynamics
- Geopolitics
- Disasters

Rethink Redesign

- China + 1
- Supplier diversification
- Manufacturer diversification
- Facility relocation
- Just in Time → Just in case

However, there is a general lack of policies/procedures/methodologies/knowledge base which can facilitate the shift from existing supply chain structure to a better and more desirable supply chain structure.

Research need

Transformation of the conventional supply chain management into sustainable supply chain management generates tremendous pressure on firms to bring changes to their existing supply chains order to meet the current sustainability needs (Busse et al., 2017).

From the practical implementation point of view, there should be policies/procedures/methodologies/knowledge base in place which can facilitate the shift towards sustainability while encouraging companies to invest in designing and/or redesigning their existing supply chains with sustainability consideration.

This study focuses on the developing methodologies and knowledge base that will enable companies to understand,

(1) the implications of incorporating different components of sustainability and

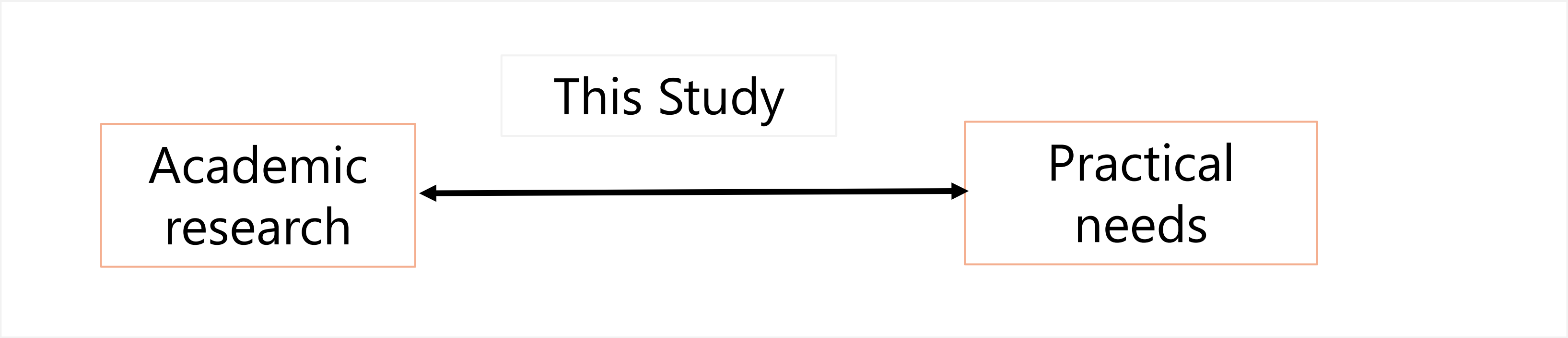
(2) how to design new and/or redesign their existing supply chains.

Research novelty

This is the first study that addresses the gaps and research needs mentioned above by developing three models that can sequentially incorporate different components of sustainability and illustrate the impact of incorporating them on network design decisions.

Research goal

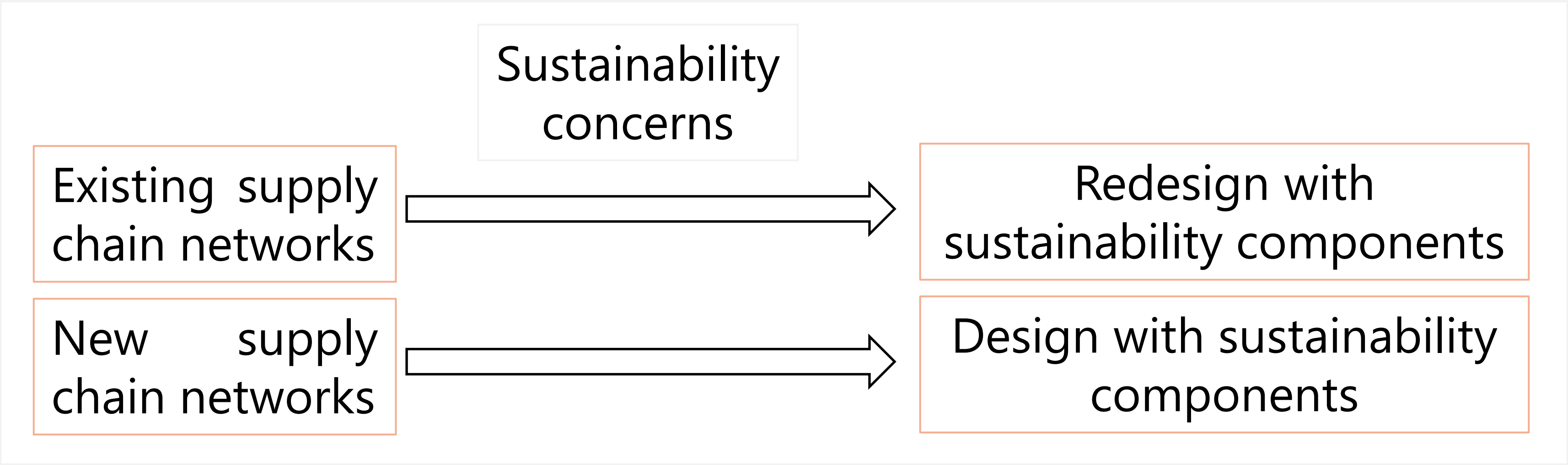
The goal of this study is to develop methodologies that acts as a bridge between academic research and practical needs to enable informed sustainable supply chain network design related decision making.



This Study

Academic research

Practical needs



Sustainability concerns

Existing supply chain networks

Redesign with sustainability components

New supply chain networks

Design with sustainability components

Research objectives

The specific objectives of this research are,

1. To develop supply chain network design models considering different components of sustainability.

2. To illustrate the impact of integrating different components of sustainability on supply chain network design decision in terms of,

   - Cost
   - Emission
   - Demand satisfaction
   - Location of facilities
   - Selection of suppliers
   - Allocation of facilities to customer zones

Literature Review

Literature review (1)

The concept of sustainable supply chain has been by far the most improperly used, as the different authors have primarily focused their attention on the economic and environmental dimensions, often combined, but few addressed the social dimension simultaneously (Seuring, 2013; Brandenburg et al., 2014; Bradenburg and Rebs, 2015, Fahimnia and Jabbarzadeh, 2016; Barbosa-Povoa et al., 2018).

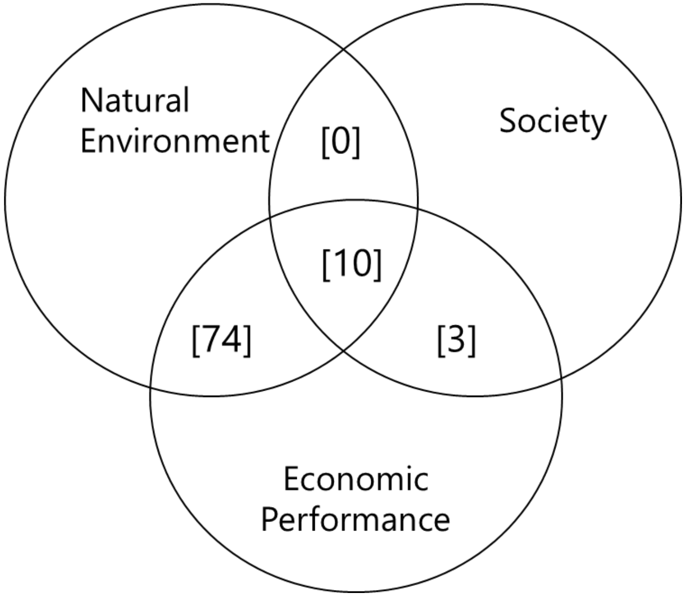


Figure 5: Distribution of papers with respect to the 3 dimensions of sustainability
(Eskandarpour et al., **2015**)

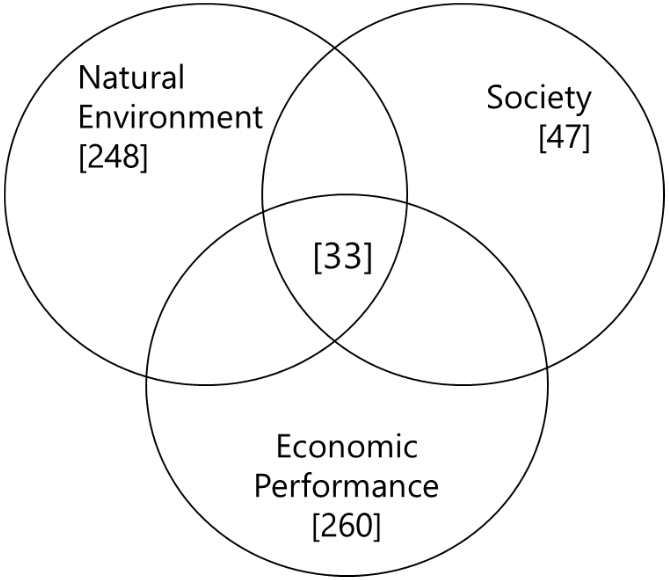


Figure 6: Distribution of papers with respect to the 3 dimensions of sustainability
(Asgharizadeh et al., **2019**)

Literature review (2)

In the existing literature, there seems to be unanimity in the choice of objective function in terms of economic and environmental components. On the contrary, different studies seem to be using different types of indicators to measure social component of sustainability.

Sustainability component	Measures/Indicators used	References
Economic	Minimization of cost or maximization of profit	Lee et al., 2010; Chaabanen et al., 2012; Validi, et al. 2014; Mari et al., 2014; Nagurney 2015; Babazadeh, et al., 2018; Wang, et al., 2018
Environmental	Minimization of CO_2 and GHG emission	
Social	Maximization of customer service reliability	Xifenga et al., 2013; Chen and Andresen, 2014; Bairamzadeh, et al., 2015; Varseia and Polyakovskiy, 2017; Motaa et al., 2018
	Minimization of employee injuries	
	Maximization of number of jobs generated	

There is no unanimous measure for quantitatively measuring social component of sustainability.

Research gap

- First, although the number of studies in the field is increasing, the number of studies accounting for all three components of sustainability in the design process are still limited.

- Second, while there is a preconceived notion that sustainable supply chains are desirable there is a general lack of studies which have

  - developed models and methodologies that enables sequential incorporation of all three components of sustainability;

  - illustrated the impact of sequentially incorporating all three components of sustainability in the network design decisions.

- Studies have generally incorporated one or more components of sustainability and presented the results without comparison with the existing structure of the network.

  - From a decision makers point of view, a strategic decision like network design is both cost, time and resource intensive therefore a detailed comparison with the existing system becomes indispensable.

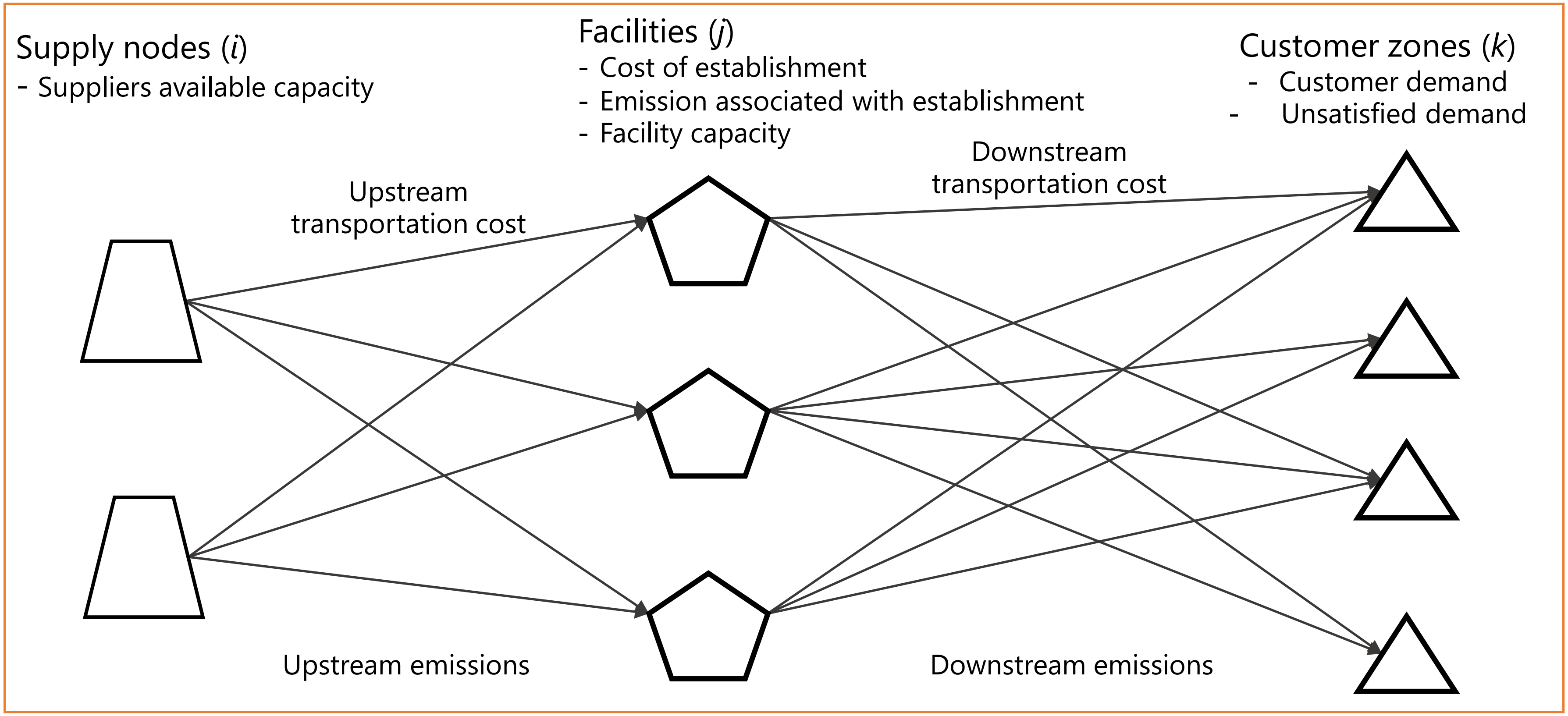
Problem description

Increasing regulations for carbon and waste management and greater corporate social responsibility is necessitating organizations to redesign their existing supply chain networks such that they are conscious of their environmental and social impacts in addition to cost minimizing or profit maximizing objectives.

Problem description

We consider an organization operating a three-echelon supply-distribution network for a particular product.

- The supply – distribution network consists of supply nodes, facilities, and customer zones denoted by *i, j* and *k* respectively.
- The product is sourced from a number of suppliers (*i*) and must be dispatched to a number of customer zones (*k*) via facilities (*j*).



Supply nodes (*i*)

- Suppliers available capacity

Facilities (*j*)

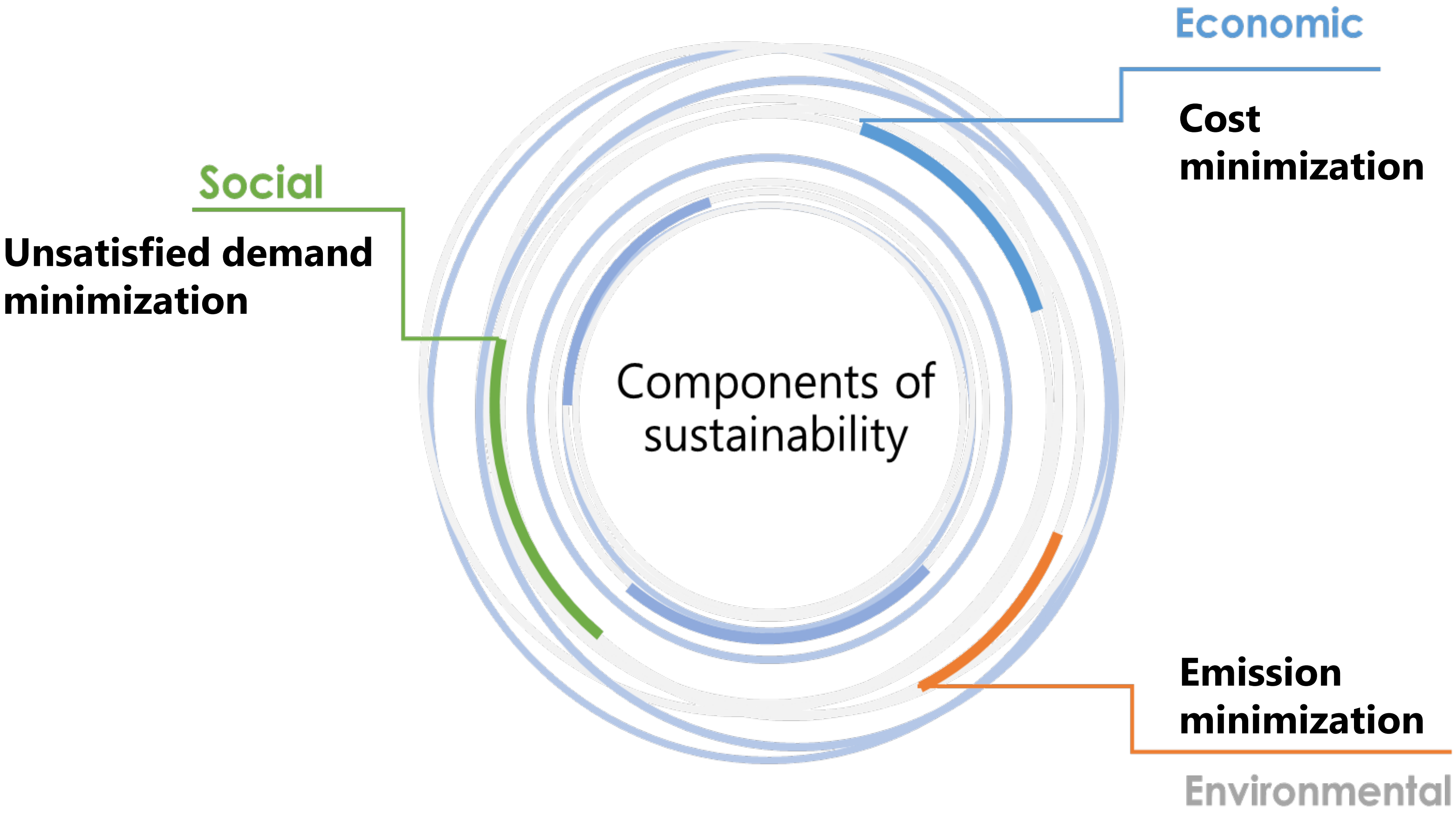
- Cost of establishment
- Emission associated with establishment
- Facility capacity

Customer zones (*k*)

- Customer demand
- Unsatisfied demand

Figure 7: Structure of proposed supply chain network

Measures of the components of sustainability



Components of sustainability

Economic

Cost minimization

Social

Unsatisfied demand minimization

Emission minimization

Environmental

Model formulation

We formulate three different models to enable incorporation of different components of sustainability in SCND and illustrate the sequential impact of its incorporation.

Model formulation

Option I: Considers economic component

Cost minimization

Option II: Considers economic and environmental components

Cost minimization

Emission minimization

Option III: Considers sustainability

[Economic, environmental and social components]

Cost minimization

Emission minimization

Unsatisfied demand minimization

Model assumptions:

- A single product is produced and distributed throughout the network.
- The location of supply nodes and customer zones are fixed.
- Supply nodes and facilities can be configured at various capacity levels.
- Carbon-dioxide (CO_2) emission depends on the type and size of vehicle
    - ➢ hence mode choice affects the environmental impact.
- Vehicle type L is used to move goods in the upstream supply chain and vehicle type S is used to move goods in the downstream distribution chain.
- All vehicles are considered carrying full truck-load.

Nomenclature

Sets

I	set of supply points
J	set of facilities
K	set of customer zones

Parameters

F_j : Fixed costs incurred during the establishment of facility j
e_j : Fixed emission associated with the establishment of facility j
TC_{ij} : Total transportation cost from supply node i to facility j
TC_{jk} : Total transportation cost from facility j to customer zone k
u_{ij}^{L} : Unit transportation cost from supply node i to facility j per km using vehicle type L
u_{jk}^{S} : Unit transportation cost from facility j to customer zone k per km using vehicle type S
v^L, v^S : Capacity of vehicle type L and S
d_{ij} : Distance between supply node i to facility j
d_{jk} : Distance between facility j to customer zone k
e_{ij} : Total carbon emission from supply node i to facility j (kg/unit)
e_{jk} : Total carbon emission from facility j to customer zone k (kg/unit)
co^L : Average CO_2 emission per ton-km by vehicle type L
co^S : Average CO_2 emission per ton-km by vehicle type S
S_i : Capacity of supply node i
W_j : Total number of facilities
d_k : Demand at customer zone k

Variables

q_{ij} : Quantity of goods shipped from supply node i to facility j
q_{jk} : Quantity of goods shipped from facility j to customer zone k
y_j : A binary variable which equals 1 if a facility is open in location j and 0 otherwise

Model formulation for Option I: Considers efficiency

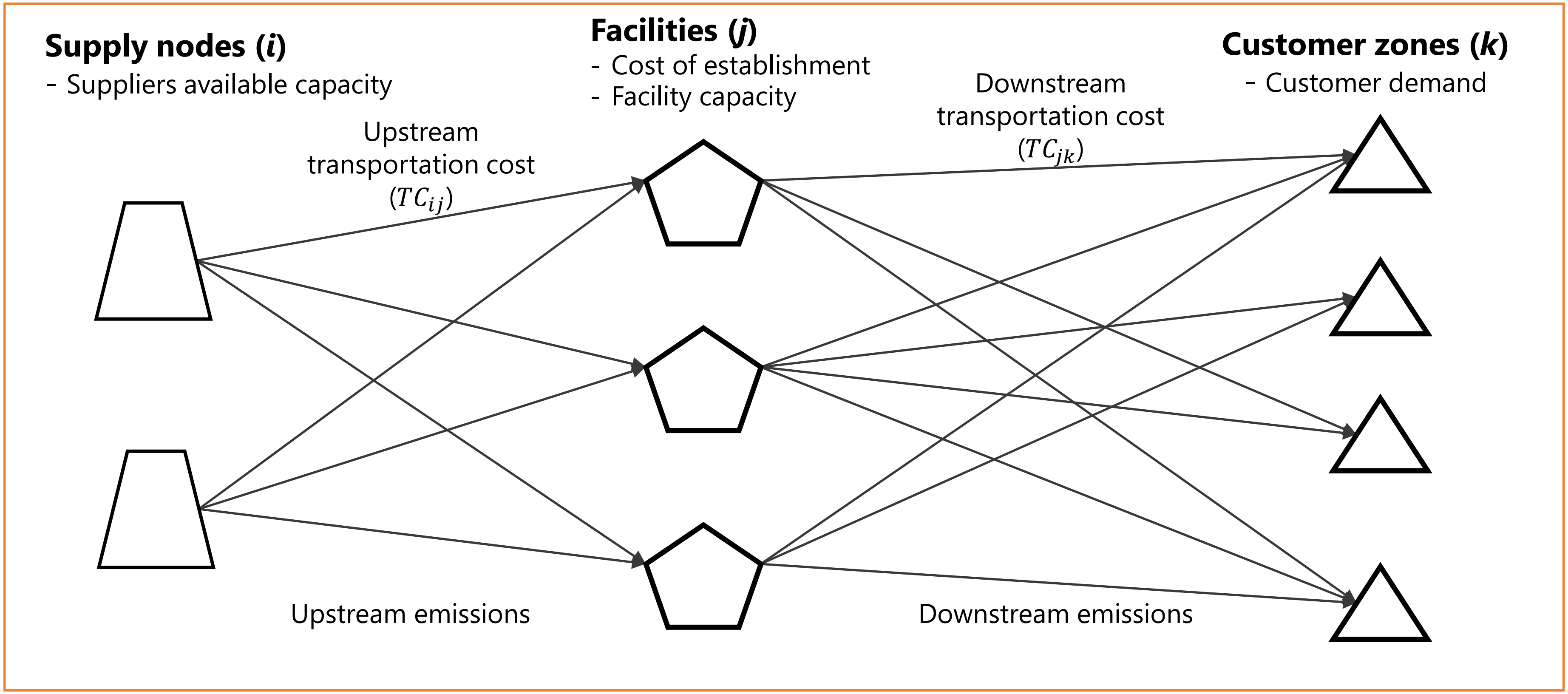
Minimize total cost of establishing a supply chain network,

Transportation cost of moving goods from supply nodes to facilities

$$O_1 = \sum_j F_j y_j + \sum_i \sum_j TC_{ij} + \sum_j \sum_k TC_{jk} \tag{1-1}$$

Fixed cost of opening facilities

Transportation cost of moving goods from facilities to customer zones



Supply nodes (*i*)
- Suppliers available capacity

Facilities (*j*)
- Cost of establishment
- Facility capacity

Customer zones (*k*)
- Customer demand

Upstream transportation cost (TC_{ij})

Downstream transportation cost (TC_{jk})

Upstream emissions

Downstream emissions

Model formulation for Option I: Considers efficiency

Where,

$$TC_{ij} = \frac{u_{ij}^{L} \times d_{ij}}{v^{L}} \times q_{ij} \qquad (1\text{-}2)$$

$$TC_{jk} = \frac{u_{jk}^{S} \times d_{jk}}{v^{S}} \times q_{jk} \qquad (1\text{-}3)$$

Constraints

1. Flow conservation constraint,

$$\sum_k q_{jk} - \sum_i q_{ij} = 0 \qquad \forall j \in \mathrm{J} \qquad (1\text{-}4)$$

2. Availability constraints

$$\sum_j q_{ij} \le S_i \qquad \forall i \in \mathrm{I} \qquad (1\text{-}5)$$

$$\sum_i q_{ij} \le W_j \qquad \forall j \in \mathrm{J} \qquad (1\text{-}6)$$

$$\sum_k q_{jk} \le W_j \qquad \forall j \in \mathrm{J} \qquad (1\text{-}7)$$

3. Demand constraint

$$\sum_j q_{jk} = d_k \qquad \forall k \in \mathrm{K} \qquad (1\text{-}8)$$

4. Constraints that depict nature of decision variables

$$q_{ij} \ge 0 \qquad \forall i \in \mathrm{I}, j \in \mathrm{J} \qquad (1\text{-}9)$$

$$q_{jk} \ge 0 \qquad \forall j \in \mathrm{J}, k \in \mathrm{K} \qquad (1\text{-}10)$$

$$y_j \in \{0,1\} \qquad \forall j \in \mathrm{J} \qquad (1\text{-}11)$$

Model formulation for Option II: Considers efficiency & environment

Minimize total cost and environmental emission associated with establishing a supply chain network,

$$O_1 = \sum_j F_j y_j + \sum_i \sum_j TC_{ij} + \sum_j \sum_k TC_{jk} \qquad (1\text{-}1)$$

CO_2 emission associated with moving goods from supply nodes to facilities

$$O_2 = \sum_j e_j y_j + \sum_i \sum_j e_{ij} + \sum_j \sum_k e_{jk} \qquad (2\text{-}1)$$

Emission associated with opening facilities

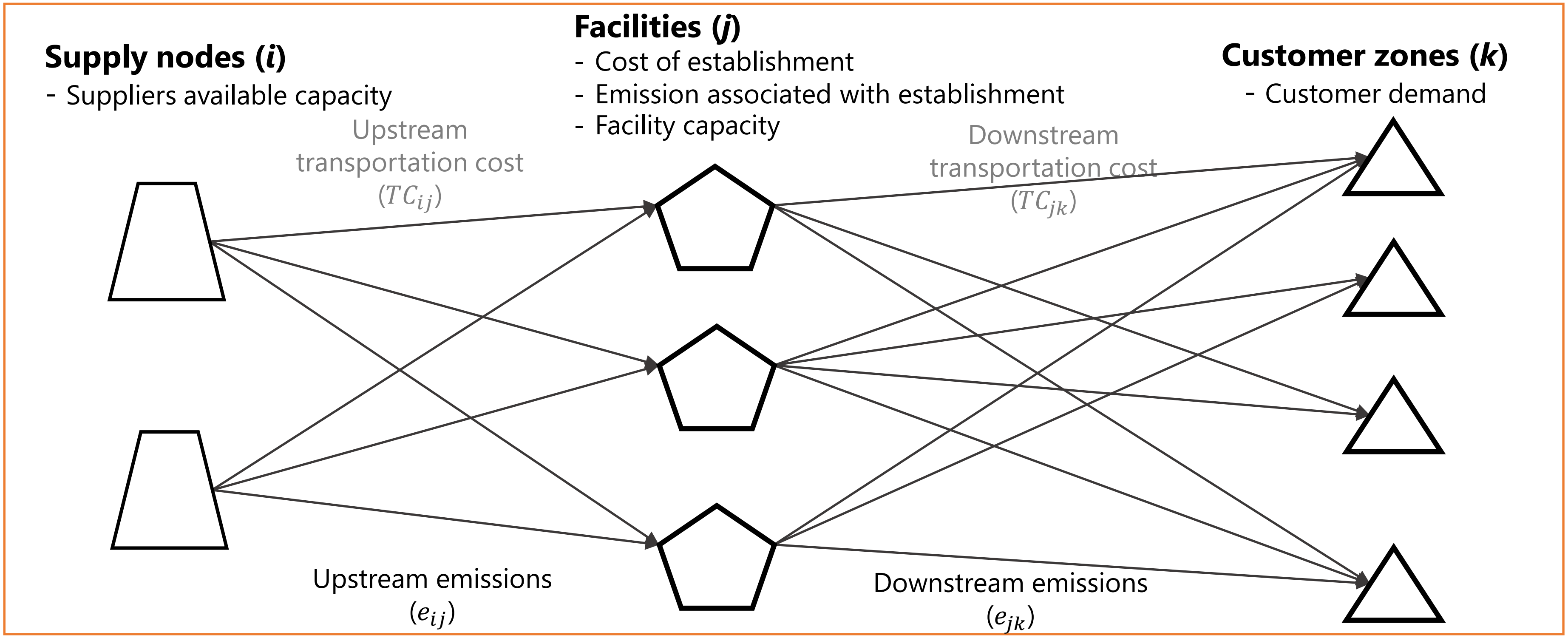
CO_2 emission associated with moving goods from facilities to customer zones

Where

$$e_{ij} = q_{ij} \times co^L \times d_{ij} \qquad (2\text{-}2)$$

$$e_{jk} = q_{jk} \times co^S \times d_{jk} \qquad (2\text{-}3)$$

subject to (1-2), (1-3), and (1-4) to (1-11).



Supply nodes (*i*)
- Suppliers available capacity

Facilities (*j*)
- Cost of establishment
- Emission associated with establishment
- Facility capacity

Customer zones (*k*)
- Customer demand

Model formulation for Option III: Considers sustainability

Minimize total cost, environmental emission associated with establishing a supply chain network and total unsatisfied demand,

$$O_1 = \sum_j F_j y_j + \sum_i \sum_j TC_{ij} + \sum_j \sum_k TC_{jk} \quad (1\text{-}1)$$

$$O_2 = \sum_j e_j y_j + \sum_i \sum_j e_{ij} + \sum_j \sum_k e_{jk} \quad (2\text{-}1)$$

$$O_3 = \sum_k d_k - \sum_j \sum_k q_{jk} \quad (3\text{-}1)$$

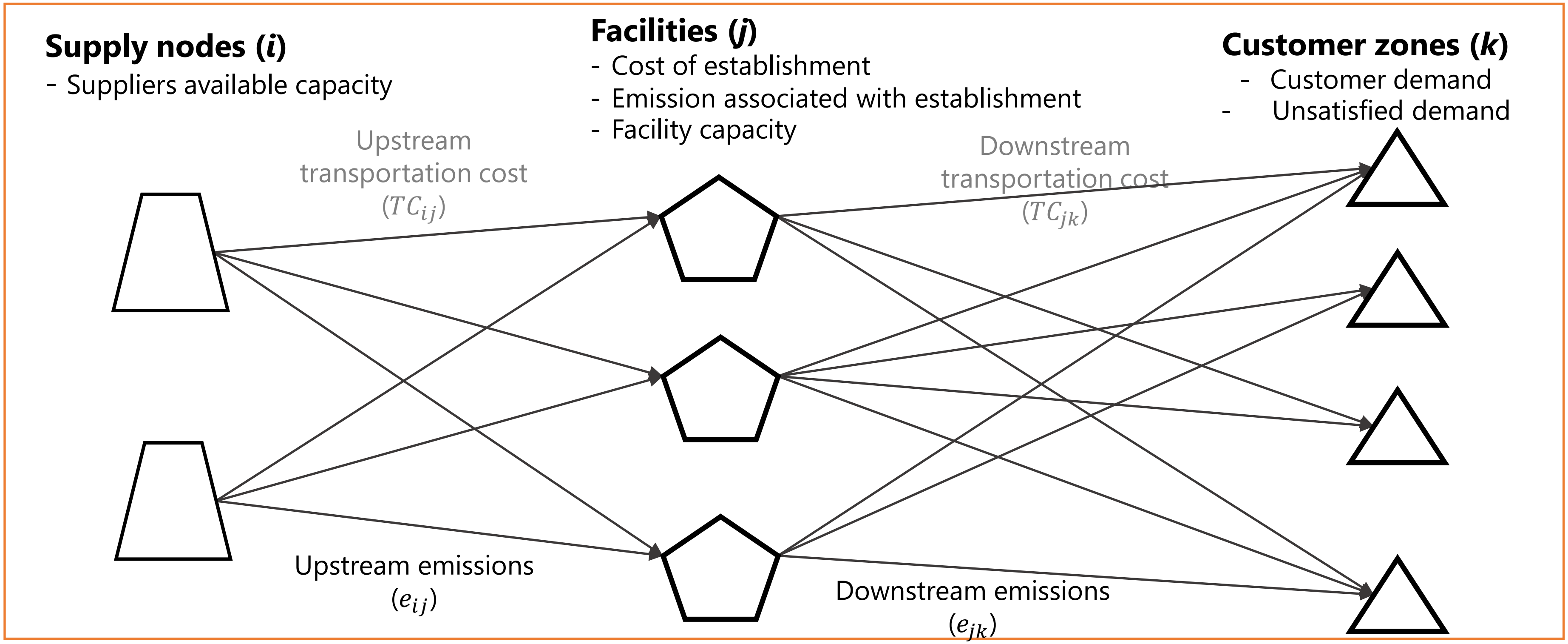
Total demand for goods

Total goods distributed

subject to (1-2), (1-3), (1-4) to (1-7), (1-9) to (1-11),(2-2), (2-3) and

Demand constraints

$$\sum_j q_{jk} \leq d_k \qquad \forall k \in K \qquad (3\text{-}2)$$



Supply nodes (*i*)

- Suppliers available capacity

Facilities (*j*)

- Cost of establishment
- Emission associated with establishment
- Facility capacity

Customer zones (*k*)

- Customer demand
- Unsatisfied demand

Upstream transportation cost (TC_{ij})

Downstream transportation cost (TC_{jk})

Upstream emissions (e_{ij})

Downstream emissions (e_{jk})

Solution approach

As we are dealing with bi-objective (Option-II) and multi-objective (Option-III) optimization models, we utilize Epsilon constraint method to solve the developed models.

The optimization model for Option II is reformulated to optimize **total CO_2 emission** such that total cost is constrained to a **real value scalar** $\boldsymbol{\varepsilon_2}$.

Similarly, the optimization model for Option III is reformulated to optimize total **CO_2 emission** such that total cost and total unsatisfied demand are constrained to **real valued scalar** $\boldsymbol{\varepsilon_2}$ **and** $\boldsymbol{\varepsilon_3}$.

Numerical illustration

To show the usefulness of the three models developed in this study we illustrate by means of numerical examples in coming slides.

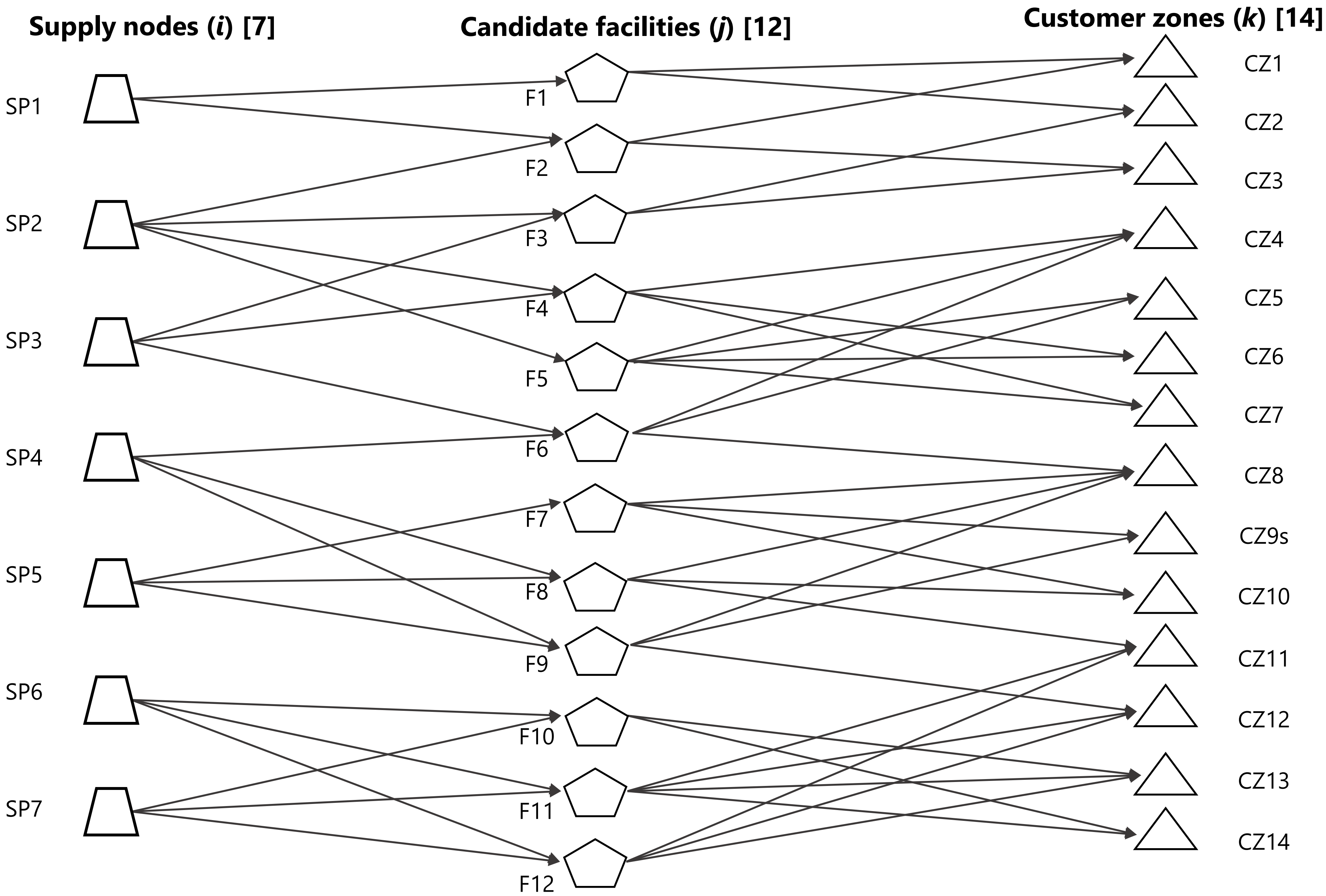
Model inputs

- We consider a three level supply-distribution network.
- Supply nodes, facilities, and customer zones are located at different nodes.
- There are 7 supply nodes, 12 candidate facilities, and 14 customer zones.
- The capacities of supply nodes and candidate facilities is given.
- Fixed cost and emission associated with facility establishment is given.
- Unit transportation cost from one echelon to the other and CO_2 emission per ton-km for road transport is also given.
- Each customer zone has a known demand.

Table 1: Model inputs

List of input parameters		
Supply nodes	**Candidate facilities**	**Customer zones**
SP1	F1	CZ1
SP2	F2	CZ2
SP3	F3	CZ3
SP4	F4	CZ4
SP5	F5	CZ5
SP6	F6	CZ6
SP7	F7	CZ7
	F8	CZ8
	F9	CZ9
	F10	CZ10
	F11	CZ11
	F12	CZ12
		CZ13
		CZ14

Supply chain network structure for numerical illustration



Results: Option I (1)

Location of facilities

Total cost of the supply chain network

Option I model resulted in the selection of facilities **F4, F5, F6**, and **F7** to fulfill the demand of all 14 customer zones.

Total cost	**8.734 million USD**
Fixed cost	4 million USD
Upstream transportation cost (Cost of transporting goods from supply nodes to facilities)	0.314 million USD
Downstream transportation cost (Cost of transporting goods from facilities to customer zones)	4.42 million USD

Results: Option I (2)

Supply nodes selection

Upstream allocation

Downstream allocation

- Among the seven supply nodes considered in this numerical illustration, the model only selected **SP1** and **SP7**.
- The largest proportion of the customer demand is fulfilled by **F4** followed by **F6**, **F5**, and **F7**, highlighting the order of significance of the facilities based on the demand fulfillment rate.

Table 2: Option I: Supply nodes selection, upstream and downstream allocation

Supply nodes	Upstream allocation (10,000 units)	Facilities selected	Downstream allocation (10,000 units)													
			CZ1	CZ2	CZ3	CZ4	CZ5	CZ6	CZ7	CZ8	CZ9	CZ10	CZ11	CZ12	CZ13	CZ14
SP1	350	**F4**					349		1.15							
	250	**F5**	38.2		37.3			76.4					40.5			57.6
	265.42	**F6**							92.5	84		29.6			59.2	
SP7	208.29	**F7**	22.7	67.2		54.2					55.5			8.7		

Results: Option II (1)

Location of facilities

Total cost

Total CO_2 emission

- When focusing on minimizing total cost, option II model resulted in the selection of facilities **F4, F5, F6**, and **F7** to fulfill the demand of all 14 customer zones.
- When focusing on minimizing total CO_2 emission, option II model resulted in the selection of facilities **F1, F4, F5**, and **F6** to fulfill the demand of all 14 customer zones.

	Minimum total cost (N)	**Minimum CO_2 emission (M)**
Total cost	8.734 million USD	9.69 million USD (7.47% ↑)
Total CO_2 emission	50 tons	38 tons (21% ↓)
Network configuration	F4, F5, F6, and F7	F1, F4, F5, and F6

Results: Option II (2)

Supply nodes selection

Upstream allocation

Downstream allocation

- Among the seven supply nodes considered in this numerical illustration, the model only selected **SP1** and **SP7**.
- The largest proportion of the customer demand is fulfilled by **F4** followed by **F6**, **F5**, and **F1**, highlighting the order of significance of the facilities based on the demand fulfillment rate.

Table 3: Option II: supply nodes selection, upstream and downstream allocation (minimize CO_2 emission)

Supply nodes	Upstream allocation (10,000 units)	Facilities selected	Downstream allocation (10,000 units)													
			CZ1	CZ2	CZ3	CZ4	CZ5	CZ6	CZ7	CZ8	CZ9	CZ10	CZ11	CZ12	CZ13	CZ14
SP1	185.57	**F1**		67.21		54.21					55.49			8.66		
	350	**F4**	1.15				348.85									
	250	**F5**	38.21		37.31			76.39					40.53			57.56
	9.6134	**F6**	21.57						93.63	84.1		29.6			59.24	
SP7	278.526															

Results: Option II (3)

Trade-off relationship between minimizing total cost and Total CO_2 emission

- A trade-off relationship between the efficiency and environmental component can be observed in Figure 8.

- A **decrease in total CO_2** emission results in an **increase in total cost** associated with the supply chain network highlighting the inverse relationship between the two objectives.

- All the other points in between the two extreme points N and M presents alternative solutions to the same problem.

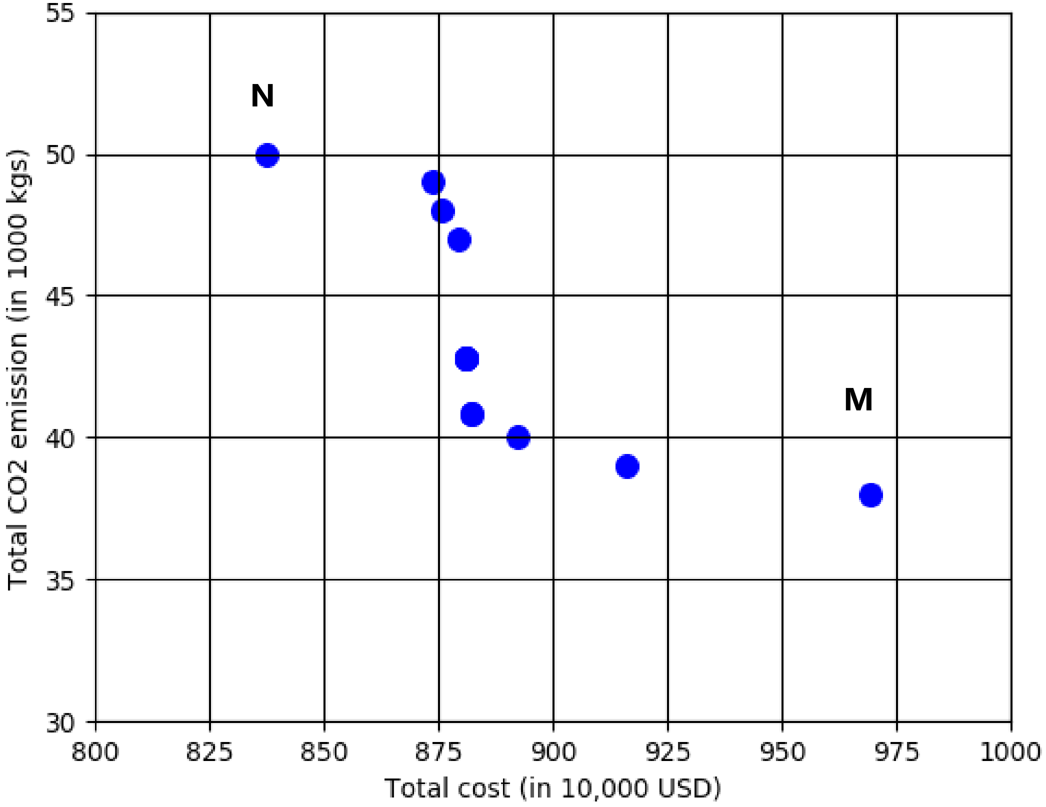


Figure 8: Results for Option II model

Results: Option III

- Figure 9 illustrates the total cost and total CO_2 emission at every value of ε_3 i.e. unfulfilled demand.
- Point A corresponds to the Option I solution where the total cost is minimized.
- Points B corresponds to one of the Option II solutions where total CO_2 emission is minimized.
- Point C corresponds to a situation where 90.68 percentage of the total demand arising from the customer zones is fulfilled.

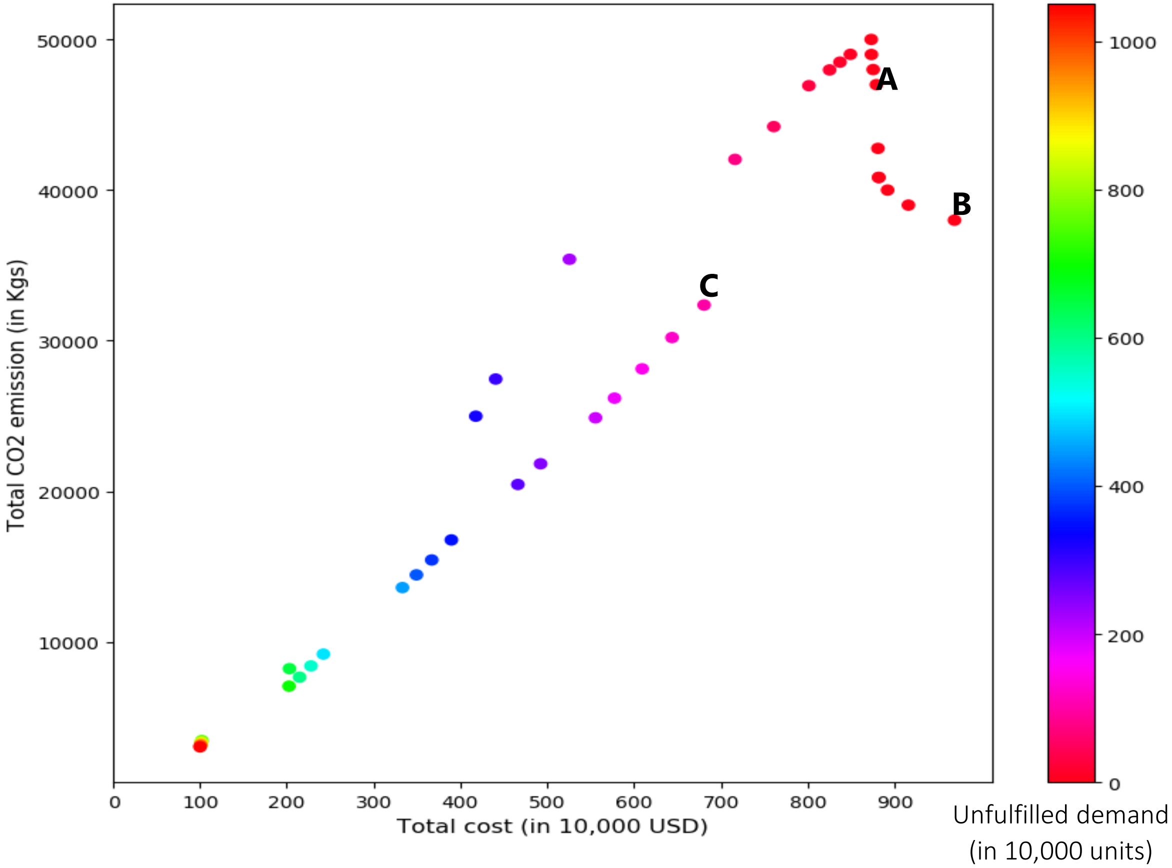


Figure 9: Result for Option III model

- From the figure, starting from the best possible situation in which all the demand is fulfilled, a gradual increase in total cost and total CO_2 emission can be observed with decreasing values of total unfulfilled demand.
- Higher demand fulfillment will incur high total cost and high total CO_2 emission.

Comparison of Option I, II, and III results

Observation 1: Supply chain network configuration is sensitive to incorporation of components of sustainability.

Comparison of the optimal results

	Total cost (million USD)	Total CO_2 emission (tons)	Total unsatisfied demand (million units)	Network configuration
Point **A** (Option I)	8.734	50	N/A	F4, F5, F6, and F7
Point **B** (Option II)	9.69	38	N/A	F1, F4, F5, and F6
Point **C** (Option III)	6.81	32.36	1 (9.32%)	F1, F4, F5, and F6

Trade-off between option I, II, and III

Observation 2: A trade-off relationship between the different components of sustainability exists.

Comparison of optimal results	**Cost**	**Emission**	**Unsatisfied demand**
Option I (1 sustainability component)	18.63% ↓	35.28% ↓	9.32% ↑
Option III (3 sustainability components)			
Option II (2 sustainability components)	29.72% ↓	14.84% ↓	9.32% ↑
Option III (3 sustainability components)			

Comparison of allocation results (1)

Observation 3: Selection of suppliers and network's supply and distribution structure is sensitive to incorporation of sustainability components.

Table 2: Option I: Supply nodes selection, upstream and downstream allocation

Supply nodes	Upstream allocation (10,000 units)	Facilities selected	Downstream allocation (10,000 units)													
			CZ1	CZ2	CZ3	CZ4	CZ5	CZ6	CZ7	CZ8	CZ9	CZ10	CZ11	CZ12	CZ13	CZ14
SP1	350	F4					349		1.15							
	250	F5	38.2		37.3			76.4					40.5			57.6
	265.42	F6							92.5	84		29.6			59.2	
SP7	208.29	F7	22.7	67.2		54.2					55.5			8.7		

Table 3: Option II: supply nodes selection, upstream and downstream allocation (minimize CO_2 emission)

Supply nodes	Upstream allocation (10,000 units)	Facilities selected	Downstream allocation (10,000 units)													
			CZ1	CZ2	CZ3	CZ4	CZ5	CZ6	CZ7	CZ8	CZ9	CZ10	CZ11	CZ12	CZ13	CZ14
SP1	185.57	F1		67.21		54.21					55.49			8.66		
	350	F4	1.15				348.85									
	250	F5	38.21		37.31			76.39					40.53			57.56
	9.6134	F6	21.57						93.63	84.1		29.6			59.24	
SP7	278.526															

Comparison of network configuration	Location	Capacities	Allocation
Option I	▪ Same location of suppliers ▪ Different location of facilities	Different capacities of facilities	Different allocation of goods both upstream and downstream
Option II			

Comparison of allocation results (2)

Observation 3: Selection of suppliers and network's supply and distribution structure is sensitive to incorporation of sustainability components.

Table 3: Option II: supply nodes selection, upstream and downstream allocation (minimize CO_2 emission)

Supply nodes	Upstream allocation (10,000 units)	Facilities selected	Downstream allocation (10,000 units)													
			CZ1	CZ2	CZ3	CZ4	CZ5	CZ6	CZ7	CZ8	CZ9	CZ10	CZ11	CZ12	CZ13	CZ14
SP1	185.57	F1		67.21		54.21					55.49			8.66		
	350	F4	1.15				348.85									
	250	F5	38.21		37.31			76.39					40.53			57.56
	9.6134	F6	21.57						93.63	84.1		29.6			59.24	
SP7	278.526															

Table 4: Option III: Supply node selection, upstream and downstream allocation (sustainability)

Supply nodes	Upstream allocation (10,000 units)	Facilities selected	Downstream allocation (10,000 units)													
			CZ1	CZ2	CZ3	CZ4	CZ5	CZ6	CZ7	CZ8	CZ9	CZ10	CZ11	CZ12	CZ13	CZ14
SP1	185.57	F1		67.21		54.21					55.49			8.66		
	350	F4					348.85		1.15							
	188.14	F6							74.67	84.1					29.37	
	176.29	F5	60.93		37.31			76.39	17.81							57.56
SP5	73.71															

Comparison of network configuration	Location	Capacities	Allocation
Option II	▪ Different location of suppliers ▪ Same location of facilities	Similar capacities of the facilities	Similar allocation strategies
Option III			

Summary and Conclusion

Summary

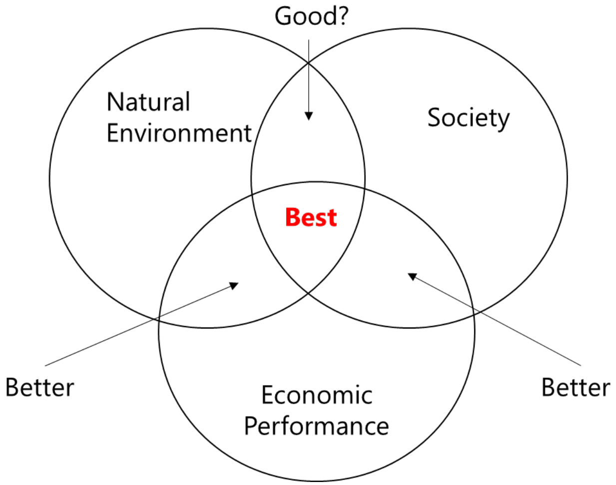
- Developed three models, Option I, Option II, and Option III by incorporating economic, environment and social components of sustainability sequentially.
- Illustrated the impact of sequentially integrating different components of sustainability in supply chain network configuration decisions as follows:
  - optimal number and location of facilities;
  - optimal supply nodes to be included in the network configuration;
  - quantity of goods to be shipped from each supplier to the facility and from facility to the customer zones and,
  - the number of facilities allocated to each customer zones.
- Compared the results of the three models.
- Illustrated the trade-off relationship that exists between the different sustainability components.

Conclusion

This study serves as a starting point for organizations/companies looking at,

- designing new supply chain networks

- redesigning existing supply chain networks with sustainability consideration.



- The graphical results in Figure 8 and 9 shows the Pareto frontier in case of more than one objective.
  - This pareto frontier provides decision-makers with a portfolio of alternative optimal solutions to choose from when making the supply chain network configuration decision.
- From a decision-maker's perspective, these ample alternatives provide an in-depth understanding of,
  - The environmental and social impacts of supply distribution network in addition to economic performance, and
  - The trade-off relationship between three components

which is essential for making informed decision.

Practical implications - 1

There is a general conception that integration of different sustainability components come at **a great cost** and **brings about significant changes** that could make companies overwhelmed. The results of this study have shown that the changes could come but not all at once in terms of

- Cost of supply chain network
- CO_2 emission
- Demand satisfaction
- Location of suppliers
- Location of facilities
- Capacities of facilities
- Allocation of goods upstream
- Allocation of goods downstream

	Total cost (million USD)	Total CO_2 emission (tons)	Total unsatisfied demand (million units)	Facility locations
Option I	8.734	50	N/A	F4, F5, F6, and F7
Option II	9.69	38	N/A	F1, F4, F5, and F6
Option III	6.81	32.36	1 (9.32%)	F1, F4, F5, and F6

Practical implications - 2

There is a general conception that integration of different sustainability components come at **a great cost** and **brings about significant changes** that could make companies overwhelmed. The results of this study has shown that the changes could come but not all at once in terms of

- Cost of supply chain network
- CO_2 emission
- Demand satisfaction
- Location of suppliers
- Location of facilities
- Capacities of facilities
- Allocation of goods upstream
- Allocation of goods downstream

Comparison of network configuration	Location	Capacities	Allocation
Option I	▪ Location of suppliers remain same ▪ Location of facilities are different	Capacities of facilities changes	Allocation of goods both upstream and downstream changes
Option III			
Option II	▪ Location of suppliers are different ▪ Location of facilities remain same	Capacities of the facilities do not change significantly	Allocation strategies remain similar
Option III			

Limitations and further studies

- The results presented and discussed in this study are specific to the problem set therefore, a more general implications cannot be generated.
    - Future studies could focus on developing more generic models.
- This study uses a very simplified measure of the social component of sustainability. A more comprehensive measure that reflects the need of the company designing/redesigning the supply chain network is desirable.
    - Future studies could focus on the use of industry and/or company specific measure for social component of sustainability.
- Case study using real data of one or more companies could provide more insightful understanding of the impacts of incorporation of sustainability components.
    - Future studies could focus on a real-life case study.

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Thank you for your attention.