DESIGN AND OPTIMIZATION OF A SUSTAINABLE CLOSED LOOP SUPPLY CHAIN NETWORK (SCLSCN): A MULTI-PRODUCT, MULTI-ECHELON MULTI-MODAL TRANSPORT AND MULTI PLANT TECHNOLOGY CONDITIONS

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Abstract

A mixed-integer mathematical model that concurrently optimizes the three intrinsic aspects of sustainability: cost, environmental effect, and social impact, was created for a general closed-loop supply chain network. The suggested innovative hybrid model is developed to incorporates several real-world aspects of SC execution, such as multi product, multi echelons, multiple production technology, and multiple means of transportation. On the GAMS/CPLEX solver, the weighted sum method is employed to solve that model after carrying out AHP to determine the weights assigned to objectives. In order to verify the accuracy of the suggested model, a case study was carried out in the context of an automotive SCND in Nigeria. The result demonstrates that model is capable of planning the SCLSCN.

Keywords: Closed loop supply chain network, Weighted-Sum, Sustainability, CO_2 Emission, Multi-objective model, Analytical Hierarchal Process

Introduction

Supply chain management (SCM) SCM is commonly defined as the effective planning, execution, and control of all activities involving customers, retailers, warehouses, manufacturers and suppliers (Cardenas-Barron and Sana, 2014). Sustainable supply chain management entails making decisions with regards to supply chain operations that meet current needs while keeping products useful in the future. When making a decision, the sustainable approach considers not only the economic benefits, but also the environmental and social consequences.

Natural resources, such as water, energy, materials and fertile land, are the foundation of our existence on Earth. Nevertheless, the rapid consumption of these sources has been damaging to the environment, involving changes in land use, waste generation and emissions into air and water. To keep this planet alive, it will be necessary to evolve our lifestyle so that we can safeguard the Earth's essential resources base and fragile ecological systems.

Environmental degradation is now recognized as the negative side effect of development and economic prosperity. The rapid depletion of minerals and natural resources, as well as non-biodegradable and hazardous wastes, have prompted governments around the world to take prompt actions. The migration or movement toward sustainable supply chain management is gaining traction around the world. This research was aimed at addressing the planning and design of a new integrated closed loop supply chain network.

A system to maximize the creation of value during a given product's entire life cycle, with dynamic recovery from different types and volumes of return over time, is established, operated and controlled by closed loop supply chain management. Presently, the automotive industry is one of the most environmentally responsible industries. Because of government-imposed stringent environmental regulations such as sustainability, the responsibility of producers in End-of-Life Vehicle (ELV) recovery, and emission regulations of the Green House Gas (GHG), the automotive industries are transitioning from traditional supply chains to CLSC. The closed loop supply chain management (CLSCM) with consideration to both environmental and social factors, has become an extremely relevant subject matter for the automotive industry.

Literature Review

A bi-objective model for constructing a network of bi-directional facilities in a logistics network in the presence of uncertainties was provided by Tavakkoli-Moghaddam, Sadri, Pourmohammad-Zia, and Mohammadi (2015). In an effort to solve the financial and environmental issues, Yadegari, Najmi, Ghomi-Avili, and Zandieh (2015) suggested a flexible mixed-integer programming model. In order to optimise all three inherent elements of sustainability at the same time, when costs, environmental impacts and social impact are taken into account concurrently, Nguyen, Zhou's and Lin (2016) created a version of MIP model for overall closed-loop supply chain network. A CLSC model designed with fuzzy decision variables that considered the optimal transit modes was proposed by Sherafati and Bashiri (2016).

In a CLSC optimization, Rezaee, Yousefi, and Hayati (2016) demonstrated effective supplier selection, order allocation, and quantity discount policy in a MILP with two objectives. A MINLP model along with solutions for location, inventory control and pricing problems of CLSC was proposed by Kaya and Urek (2016) during their research. The multi-center supply chain scheduling problem was reviewed by Behnamian and Ghomi (2016), who divided it into a variety of sub-problems. A stochastic CLSC model including scarcity cost and rework cost was studied by Moshtagh and Taleizadeh in 2017. For both manufactured and remanufactured products, they considered a quality-based rate of return with varying expectation. In a textile company, the prospect of closing the chain and the impact on the chain's revenues were investigated by Masoudipour et al. (2017).

A CLSC design challenge including many hierarchies of facilities, including suppliers, manufacturing facilities, distribution hubs, consumer zones, collecting centers, and return points was presented by Soleimani et al. (2017). The return of raw materials, component recovery, and product remanufacturing were three sorts of return alternatives that the model expressly underlined.

For the CLSC network issue, Shi et al. (2017) developed a Multi-Objectives MIP model. Cost and network responsiveness are both taken into consideration simultaneously. A structured Mixed integer programing model of a CLSC design issue formulation for the production of edible oil was presented by Dehghan et al. (2018). Blended uncertainties were considered in this regard. Using a dual-channel CLSC network with the

Stackelberg game theory, Zeballos, Mendez, and Barbosa-Povoa (2018) studied market performance effect on optimal decisions and economic advantages of member of the SC. Taleizadeh et al. (2018) employed a multiple stage mixed integer programming technique in their network to address the difficulties of product and network design for a multiple product, multiple echelon, and multiple periods of a closed loop supply chain network.

For a multi-echelon and multi-period CLSC network, Pourjavad and Mayorga (2018) introduced a model based on FMOMILP that simultaneously optimizes cost, emmision consequences and boosting social implications. Zhen et al. (2019) suggested a unified perspective for creating a green and sustainable CLSC network under uncertain demand in a bi objective model. It was proposed a bi-objective optimization model. A mixed integer linear programming model was suggested to determine the location, allocation, and pricing of Atabaki et al. (2019)'s multi-stage closed-loop supply network, which comprises both dedicated and hybrid facilities.

A multi-stage MIP model was developed by Baptista et al. (2019) for the design of a multi-period multiproduct CLSC network. Risk management at various time periods was taken into account when solving models. A multi echelon closed-loop supply chain (CLSC) comprising various consumers, tier-one suppliers, tier two suppliers, and a manufacturer was developed by Hasanov et al. (2019). In order to lower overall logistical expenses as well as vehicle and client waiting times, A cold chain-based optimization model for the encompassing low-carbon location-routing problem was presented by Leng et al. (2020). For perishable goods, Goli et al. (2020) developed a multi-product, multi-level and multi-period CLSC network that is sustainable.

For an environmentally conscious VRP with interim depots for varying urban fuel usage, traffic settings, variable demand, and time windows of services for perishable goods, Tirkolaee et al. (2020) proposed a revolutionary mixed-integer linear programming (MILP) model. A model was provided by Zhang et al. (2021) to assist in choosing a location for cold chain shipping facilities. The model was solved using a cloud particle swarm optimization algorithm, and a potential site for a new center was chosen. An emission trading-based integrated LRIP model was proposed by Li et al. in 2022. The NSGA-II was improved in order to resolve the model. In order to examine the SC response to disaster occurrences, Katsoras and Georgiadis (2022) proposed a System Dynamics (SD)-based analysis for the operation of CLSCs. A sustainable closed-loop supply chain (CLSC) for fish was examined by Fasihi et al. in 2023 because of the fish's considerable worth in the family nutrition basket, perishability nature, and the significance of waste recovery.

Methodology

Problem Description

Figure 1 depicts the closed loop supply chain (CLSC) network under examination. In the forward chain, we have set of suppliers $s \in$, multiple brands of product $l \in L$, sets of plants $p \in P$, utilizing a set of technologies $t \in T$, customer zones or markets $c \in C$, distribution facilities $q \in Q$, transportation modes $m \in M$, collection centers $k \in K$,, recycling centers $r \in R$ and disposal facilities $w \in W$ for disposal. The Network is shown in Figure 1.

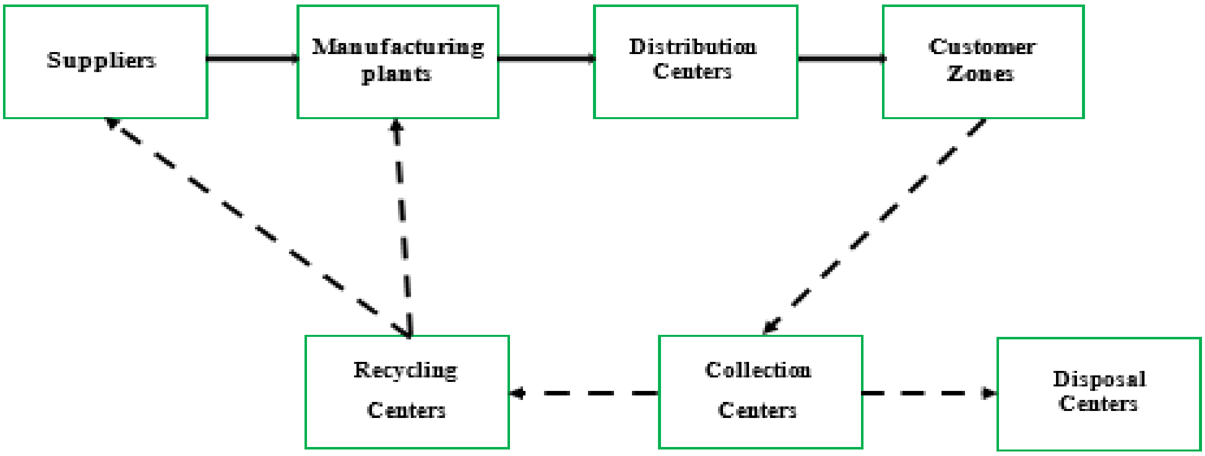

Figure 1: A Sustainable Closed-Loop Supply Chain Network (SCLSCN)

Model Assumptions

In the network configuration, the following assumptions will be made:

i. All facilities in the chain are known in relation to the number, capacity and potential location.

ii. The rate of return of used products/goods for each customer zone and the mean disposal rate are predetermined.

iii. Flows between two successive stages are authorized. There are also no concurrent flows among facilities.

Model Notations

To explain the aforementioned SCLSC network, a Mixed Integer Non-Linear Programming (MINLP) models are created using notations the listed in the Appendix.

Cost Objective

The fixed cost of establishing facilities is given by Equation (1).

$$Z_{11} = \sum_{s} FS_s ZS_s + \sum_{p,t} FM_{p,t} ZM_{p,t} + \sum_{q} FD_q ZD_q + \sum_{k} FC_k ZC_k + \sum_{r} FR_{r,t} ZR_r + \sum_{w} FY_w ZY_w + \sum_{s} FS_s ZS_s \quad (1)$$

The production cost is given by Equation (2).

$$Z_{12} = \sum_{p,l,t} CD_{p,l,t} QM_{p,l,t} \quad (2)$$

The collection and inspection cost of end-of-life product l is given by Equation (3).

$$Z_{13} = \sum_{c,k,l,m} CC_{k,l} QAC_{c,k,l,m} \quad (3)$$

The cost of recycling the end-of-life product l is given by Equation (4).

$$Z_{14} = \sum_{r,p,l,m} CR_{r,l} QRM_{r,p,l,m} \quad (4)$$

The cost of disposal of end-of-life product l is given by Equation (5).

$$Z_{15} = \sum_{k,w,l,m} CY_{w,l}\, QCY_{k,w,l,m} \quad (5)$$

The transportation cost of the entire loop is given by Equation (6).

$$Z_{16} = \sum_{s,p,l,m} CSM_{s,p,l,m} QSM_{s,p,l,m} + \sum_{p,q,l,m} CMD_{p,q,l,m} QMD_{p,q,l,m} + \sum_{q,c,l,m} CDA_{q,c,l,m} QDA_{q,c,l,m} + \sum_{c,k,l,m} CAC_{c,k,l,m} QAC_{c,k,l,m} + \sum_{k,r,l,m} CCR_{k,r,l,m} QCR_{k,r,l,m} + \sum_{r,p,l,m} CRM_{r,p,l,m} QRM_{r,p,l,m} + \sum_{k,w,l,m} CCY_{k,w,l,m} QCY_{k,w,l,m} + \sum_{r,s,l,m} CRS_{r,s,l,m} QRS_{s,p,l,m} \quad (6)$$

The cost of supply of raw material is given by Equation (7).

$$Z_{17} = \sum_{s,p,l,m} CS_{s,p,l} QSM_{s,p,l,m} \quad (7)$$

The cost objective which is expected to minimize the operational cost of the supply chain is given by Equation (8).

$$Z_1 = Z_{11} + Z_{12} + Z_{13} + Z_{14} + Z_{15} + Z_{16} + Z_{17} \quad (8)$$

Carbon Objective

The carbon emission objective provided by Equation (9) aims to optimize the total carbon dioxide emissions of the integrated closed loop supply chain.

$$Z_2 = \rho^- e^- - \rho^+ e^+ \quad (9)$$

Social Objective

Equation (10) demonstrates the social aspects of employment options that should be optimized.

$$Z_3 = Z_{31} + Z_{32} + Z_{33} + Z_{34} + Z_{35} + Z_{36} + Z_{37} \quad (10)$$

Equation (11) gives the fixed employment opportunities for the production plant.

$$Z_{31} = \sum_{p,t} fj_{p,t}\, ZM_{p,t} \quad (11)$$

Equation (12) presents the fixed job opening for establishing other facilities in the supply chain network.

$$Z_{32} = \sum_{q} fjD_q ZD_q + \sum_{k} fjC_k ZC_k + \sum_{r} fjR_r\, ZR_r + \sum_{w} fjY_w ZY_w + \sum_{s} fjS_s ZS_s \quad (12)$$

Equation (13) represents the variable employment opportunity pertaining to the quantity of good manufactured.

$$Z_{33} = \sum_{p,t,l} vo_{p,t} QM_{p,l,t} / SM_{p,l,t} + \sum_{p,t,r,q,l,m} vo_{p,t} QRM_{r,q,l,m} / SM_{p,l,t} \quad (13)$$

The variable employment opportunity created as a result of Quantity of raw material supplied is presented in Equation (14).

$$Z_{34} = \sum_{s} vo_s QBY_{s,l} / SS_{s,l} + \sum_{r,s,l,m} vo_s QRS_{r,s,l,m} / SS_{s,l} \quad (14)$$

The variable job created in regards of distribution and goods sold are presented in Equations (15) and (16) respectively.

$$Z_{35} = \sum_{q,c,l,m} vo_q QMD_{p,q,l,m} ZA_{q,c} / SD_{q,l} \quad (15)$$

$$Z_{36} = \sum_{k,c,l} vo_k ZA_{k,c} \alpha_l D_{c,l} \tag{16}$$

Other variable jobs created as a result of flow of material is given by Equation (17).

$$Z_{37} = \sum_{c,k,l,m} vo_k QAC_{c,k,l,m}/SC_{k,l} + \sum_{k,r,l,m} vo_r QCR_{k,r,l,m}/SR_{r,l} + \sum_{k,w,l,m} vo_w QCY_{k,w,l,m}/SY_{w,l} \tag{17}$$

The MILP Model for the CLSC

Equations (18) to (37) provide the model of the integrated closed loop supply chain network.

Minimize: $Z_1 = Z_{11} + Z_{12} + Z_{13} + Z_{14} + Z_{15}$ (18)

Minimize: $Z_2 = \rho^- e^- - \rho^+ e^+$ (19)

Maximize: $Z_3 = Z_{31} + Z_{32} + Z_{33} + Z_{34} + Z_{35} + Z_{36}$ (20)

Subjected to:

$$\sum_{t} QM_{p,l,t} \leq \sum_{q,m} QMD_{p,q.l,m} \quad \forall\, p,l \tag{21}$$

$$\sum_{p,m} QMD_{p,q,l,m} \leq \sum_{c,m} QDA_{q,c,l,m} \quad \forall\, q,l \tag{22}$$

$$\sum_{q,m} QDA_{q,c,l,m} \leq D_{c,l} \quad \forall\, c,l \tag{23}$$

$$\sum_{k,m} QAC_{c,k,l,m} \leq D_{c,l} \alpha_l \quad \forall\, c,l \tag{24}$$

$$\sum_{w,m} QCY_{k,w,l,m} \leq \sum_{c,m} \gamma_l QAC_{c,k,l,m} \quad \forall k,l \tag{25}$$

$$\sum_{s,m} QSM_{s,p,l,m} \leq \sum_{s,m} QRS_{r,s,l,m} + \sum_{s} QBY_{s,l} \quad \forall\, p,l,r \tag{26}$$

$$\sum_{c.m} QAC_{c,k,l,m} \leq \sum_{w,m} QCY_{k,w,l,m} + \sum_{r,m} QCR_{k,r,l,m} \quad \forall k,l \tag{27}$$

$$\sum_{p,m} QRM_{r,p,l,m} \leq \sum_{k,m} QCR_{k,r,l,m} \quad \forall r,l \tag{28}$$

$$\sum_{r,m} QRM_{r,p,l,m} \leq \sum_{t} QM_{p,l,t} \quad \forall\, p,l \tag{29}$$

$$\sum_{s,m} QSM_{s,p,l,m} \leq \sum_{t} QM_{p,l,t} \quad \forall\, p,l \tag{30}$$

$$\sum_{l} S_l QM_{p,l,t} \leq SM_{p,t,l} ZM_{p,t} \quad \forall\, p,t \tag{31}$$

$$\sum_{p,l,m} S_l QMD_{p,q,l,m} \leq SD_{q,l} ZD_q \quad \forall\, q \tag{32}$$

$$\sum_{s,l,m} SS_l QSM_{s,p,l,m} \leq SM_{p,t,l} ZM_{p,t} \quad \forall\, k,p \tag{33}$$

$$\sum_{k,l,m} S_l QCR_{k,r,l,m} \leq SR_r ZR_r \quad \forall\, r \tag{34}$$

$$\sum_{k,l,m} S_l QCY_{k,w,l,m} \leq SY_w ZY_w \qquad \forall\, w \tag{35}$$

$$\sum_{t} ZD_{p,t} \leq 1 \qquad \forall\, p \tag{36}$$

$$\begin{aligned}\sum_{p,l,t} EM_{p,l,t} ZM_{p,t} &+ \sum_{q,l} ED_{q,l} ZD_q + \sum_{k,l} EC_{k,l} ZC_k + \sum_{r,l} ER_{r,l} ZR_r + \sum_{p,q,l,m} EMD_{p,q,l,m} QMD_{p,q,l,m} \\ &+ \sum_{q,c,l,m} EDA_{q,c,l,m} QDA_{q,c,l,m} + \sum_{c,k,l,m} EAC_{c,k,l,m} QAC_{c,k,l,m} \\ &+ \sum_{k,r,l,m} ECR_{k,r,l,m} QCR_{k,r,l,m} + \sum_{r,p,l,m} ERD_{r,p,l,m} QRD_{r,p,l,m} \\ &+ \sum_{k,w,l,m} ECY_{k,w,l,m} QCY_{k,w,l,m} + e^- \leq C^{cap} + e^+ \end{aligned} \tag{37}$$

$$e^+, e^-, QMD_{p,q,l,m}, QDA_{q,c,l,m}, QAC_{c.k.l.m}, QCR_{k,r,l,m}, QCY_{k,w,l,m}, QRM_{r,p,l,m} \geq 0 \tag{38}$$

$$ZD_{p,t}, ZC_k, ZR_r, ZY_w \in \{0,1\} \tag{39}$$

Equations (21) to (37) are the constraints of the model. Constraint (21) ensures that the sum of the exiting volume of product from each plant does not surpass its production capacity. Equation (22) balances the flow of commodities in the distribution center. Equation (23) assures that the total amount of the flow exiting the distribution warehouse must fulfill the customer's demand. The relationship between market demands and product rate of product return at collection center is represented by Equation (24). The relationship between scrapped product volume and returned products collection in the collection sites is described by Equation (25). Equation (26) balances the flow of material from supplier to the manufacturing plants. The stream of product entering and exiting the collection site is controlled by Equation (27). The balanced equation of products entering and exit in the recycling center is represented by Equation (28).

According to Equation (29), the flow exiting each recycling facility must not surpass the production capacity at each plant. The balance equation of flow from the suppliers to the manufacturing plants is given by Equation (30). Equation (31) implies that the quantity of goods manufactured in each planning period at each production plant does not exceed its production capacity. Equation (32) guarantees that the sum of entering flow at distribution center does not exceed its capacity. Equation (33) is a capacity constraint that ensures the flow from the supplier does not exceed the capacity of the manufacturing plant. Equation (34) ensures that the sum of EOL product returned to collection center does not surpass the capacity of collection sites capacity. Equation (35) ensures the total amount of the flow of EOL product exiting each collection center to disposal centers does not exceed the disposal center capacity. Equation (36) ensures that only one technology type can be established at each potential plant location. Equation (37), carbon balance, Equation (38) is the non-negativity constraint. Equation (39) restricts the binary variables to 0 or 1

Solution Method

Weighted Sum Method

Using the weighted sum, the weighted sum approach merges all multi-objective functions into a single scalar, composite objective function. The general form of this method is presented in Equations (40) and (41).

Optimize: $$Z = w_1 Z_1 + w_2 Z_2 + \cdots + w_m Z_m \tag{40}$$

$$\sum_{i=1}^{m} w_i = 1 \ , \ \ w_i \in (0,1) \qquad (41)$$

A multicriteria decision making techniques is often employed to model decision maker preferences into weights. One of such methods is the Analytical Hierarchical Process (Li et al., 2020). After carrying out AHP analysis the values of the weight for the three objectives are $w_1 = 0.476$, $w_2 = 0.293$ and $w_3 = 0.231$. The model present in Equations (18) to (39) are reformulated by Equations (42) and (43).

Optimize: $Z = 0.476Z_1 + 0.293Z_2 + 0.231Z_3$ (40)

Suggested to:

Equations (21) – (39) (41)

Results And Discussion

For solving these problems, the model parameters data used in the model are uniformly distributed between their minimum and maximum values enumerated in Table 1. For the movement and flow of material between facilities three modes of transportation are possible with $M = 3$. It is well understood that varying modes of transportation emit significantly different amounts of CO_2 per ton mile. Table 2 illustrates this.

Table 1. Selected Parameter Values for the SCLSCND.

Param	Values	Unit	Param	Values	Unit
$D_{c,l}$	uniform(1500,5000)	Units	$SC_{k,l}$	uniform(1500,4000)	Unit
$FM_{p,t1}$	uniform(1500000,2000000)	Naira	$SR_{r,l}$	uniform(1300,3500)	Unit
$FM_{p,t2}$	uniform(2000000,3000000)	Naira	$SY_{w,l}$	uniform(3000,6000)	Unit
FD_q	uniform(400000,600000)	Naira	$vo_{p,t}$	Uniform(50,70)	Unit
FC_k	uniform(140000,200000)	Naira	vo_v	uniform(15,25)	Unit
FR_r	uniform(500000,900000)	Naira	α_l	uniform(0.3,0.5)	-
FY_w	uniform(350000,500000)	Naira	γ_l	uniform(0.10,0.15)	-
$fj_{p,t}$	uniform(150,300)	Naira	p^-	100	N/kg
fj_v	uniform (20,40)	Naira	p^+	200	N/kg
$SM_{p,l,t}$	uniform(3000,6000)	Unit	C^{cap}	10000	kg

Table 2. The Cost and Emission of Different Transportation Modes.

Mode	Cost (N / ton-mile)	Emission factor (kg/ton-mile)
Road	.120	0.256
Rail	980	0.0342
water	900	0.0510

Results

The general algebraic modeling system (GAMS) is used to solve the MILP. The GAMS is a complex modeling system for mathematical optimization. For modeling and addressing mixed-integer, linear, and nonlinear optimization issues. GAMS is a very appropriate technology allowing users to build reliable models that can be adjusted to suit various situations and is specifically developed for modeling applications for complex, large-scale projects. Table 3 presents the best values for the choice variables for m=1 and t=1, while Table 4 presents the best values for the objective function.

Table 3. Optimal Values of Decision Variable for the SCLSCN.

facility		$QM_{p,l,t}$			$QMD_{p,q,l,m}$			$QDA_{q,c,l,m}$			$QCY_{k,w,l,m}$			$QRS_{r,s,l,m}$		
	l	1	2	3	1	2		1	2	3	1	2	2	1	2	3
p	1	4950	4874	5112	2324	2843	2501	-	-	-	-	-	-	-	-	-
	2	1234	2343	1032	2985	2134	1865	-	-	-	-	-	-	-	-	-
q	1	-	-	-	3213	1765	1243	2200	2987	1456	-	-	-	-	-	-
	2	-	-	-	2096	3212	3123	2050	1576	1865	-	-	-	-	-	-
w	1	-	-	-	-	-	-	-	-	-	54	85	32	-	-	-
	2	-	-	-	-	-	-	-	-	-	69	43	59	-	-	-
k	1	-	-	-	-	-	-	-	-	-	854	654	389	-	-	-
	2	-	-	-	-	-	-	-	-	-	521	808	573	-	-	-
r	1	-	-	-	-	-	-	-	-	-	-	-	-	489	588	298
	2	-	-	-	-	-	-	-	-	-	-	-	-	543	615	321
s	1	-	-	-	-	-	-	-	-	-	+	-	-	125	208	58
	2	-	-	-	-	-	-	-	-	-	-	-	-	212	265	32
	3	-	-	-	-	-	-	-	-	-	-	-	-	265	95	91

Table 4. Optimized Value of the Objective Functions for the SCLSCN.

Objectives	**Values**	**Units**
Cost Objective	234,234,232.00	Naira
Carbon Objective	243,565.00	Naira
Social Objectives	3259	Jobs

Sensitivity Analysis

This section analyses how small changes in model parameter affects the solution of the model. The effect of some important and significant parameters of the MILP model on the objectives values of the problem is investigated. The demand, the return rate, and the carbon buying price are parameters considered. Figure 1 shows the sensitivity of the model solution to slight changes in demand value. Figure 2 presents the sensitivity of the objective values to slight changes in EOL return ratio value. Figure 3 visualize the sensitivity of the first and second objective to the carbon purchase price. Total cost is the sum of the first and second objective.

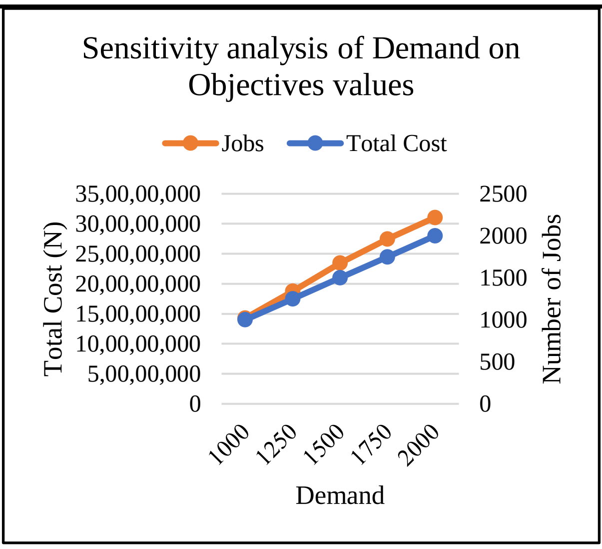

Figure 2: Sensitivity of Demand

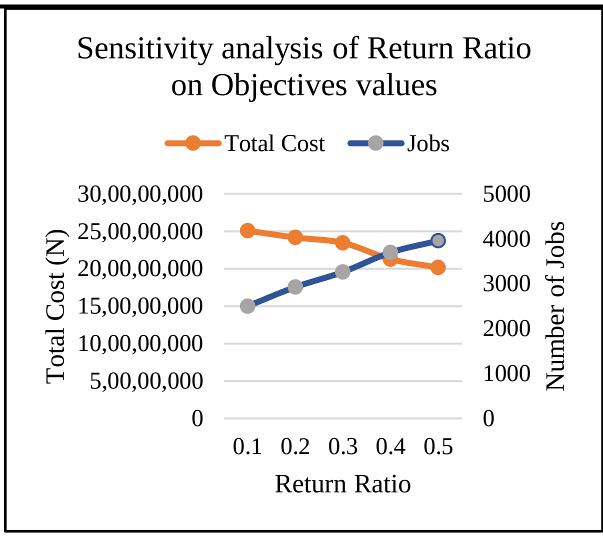

Figure 3: Sensitivity of Return ratio

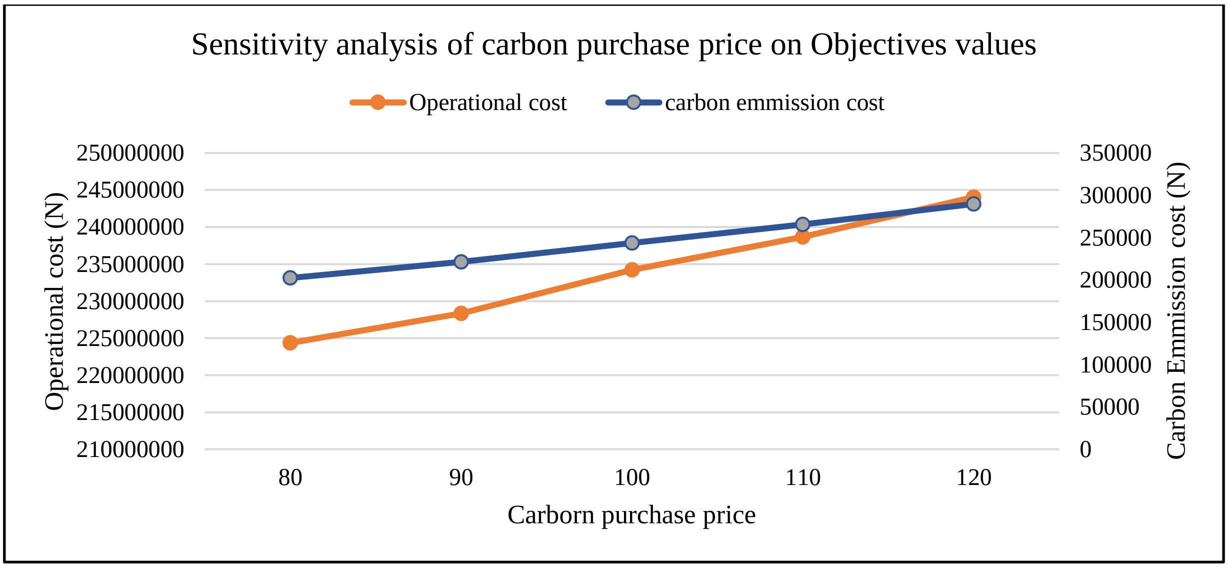

Figure 4: Sensitivity of carbon purchase price

Discussion

Table 1 presents the Optimal value of some selected decision variable that regulates the flow of material in the supply chain. The solution of the model allocated quantity of good for a product type that can be produced in the set of manufacturing plant, quantity of goods by product shipped from the manufacturing plants to set of DCs. The quantity of goods for a product type that is shipped from the DCs, the quantity of returned EOL by product that is shipped to each disposal site, the quantity of recycled material by product sent to the set of suppliers are also presented in Table 1.

The results from the GAMS program, of which are shown in Table 2, demonstrate the viability of the models in the context of a real-life case study. This mean the MILP is capable of solving the problem of the SCLSCN. When the model is solved using the first objective, the values of the objective were very low (N1,356,467.00) as compared to the value of the combined objective presented in Table 2 which optimizes all the inherent pillars of sustainability (economical, environmental and social). The very large difference in the objective value is the sacrifice the DC is willing to pay to run a SCLSCN.

Sensitivity analysis of the result of the model on slight changes in demand is shown in Figure 2. An increase in demand shows considerable increase in all objective. For the first and second objective, the increased is caused by increased production and transportation volume throughout the chain. for the third objective, the increased is cause by variable job created as a result of increase in demand. For the sensitivity of the model solution on the value of the return ratio which is shown in Figure 3, an increase in return ration value causes a decrease in total cost and an increase in the total number of job opportunities created by the chain. This is because the cost of manufacture is higher than the cost of recycling a unit product also, the more returned EOL product are send to the reverse chain so does the number of variable jobs are created by the entire chain. Lastly Figure 4 shows how the carbon purchase price affects the result of the first and second objective. As the carbon purchase price increases, the value of both objectives increases. The increase is more apparent in the second objective as the first objective shows resistance.

CONCLUSION

Although sustainability has been effectively integrated into many business operations, the SCND job appears to still be in the early stages of development, particularly when it comes to closed-loop network designs. As a result, the goal of this study is to create a MILP that explores the long-term viability of a CLSCND issue. The model is intended for cases of multi-products and multiple means of transportation and different manufacturing technology. Once the model has been created using the GAMS/CPLEX tool, it is solved using the weighted sum approach. The result indicates the effectiveness of the proposed methodology in coordinating integrated forward and reverse logistics networks in a manner that maximizes the three core sustainability principles. To solve the model, a multi-objective meta heuristic method should be applied.

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Appendix

To explain the aforementioned SCLSC network, a Mixed Integer Non-Linear Programming (MINLP) models are created using these notations:

Sets/Indices:

s	Index of supplier, $s \in S$.
p	Index of prospective sites for production plant, $p \in P$.
q	Index of prospective sites for distribution center, $q \in Q$.
c	Index of customer zones, $c \in C$.
k	Index of collection facilities, $k \in K$.
r	Index of recycling facilities, $r \in R$.
v	Index of facilities $v \in \{q, k, r, w\}$.
w	Index of disposal facilities, $w \in W$.
l	Index of products $l \in L$.
m	Index of modes of transportation, $m \in M$.
t	Index of production technologies, $t \in T$.

Parameters:

$D_{c,l}$	Customer demand at c for product l.
$R_{c,l}$	Rate of Return of used product l from customer zone c.
FS_s	Fixed cost of for maintaining supplier s contract.
$FM_{p,t}$	Fixed cost of establishing a plant at site p with technology t.
FD_q	Fixed cost of establishing site q.
FC_k	Fixed cost of establishing site k.
$FR_{r,t}$	Fixed cost of establishing site r with technology, t.
FY_w	Fixed cost of establishing and running site w.

Capacity of facilities:

$SS_{s,l}$	Capacity of supplier, s for supplying raw material for product l.
$SM_{p,l,t}$	Capacity of p for manufacturing product l with technology t.
$SD_{q,l}$	Capacity of q for holding product l.
$SC_{k,l}$	Capacity of k for collecting returned product l.
$SR_{r,l}$	Capacity of r for recycling product l.
$SY_{w,l}$	Capacity of w for disposing scrapped product l.
S_l	Unit volume of product l.
SS_l	Unit volume of raw material for product l.

Unit cost:

$CS_{s,p,l}$	Unit supply cost of raw material for product l from supplier, s to manufacturing plant, p.
$CM_{p,l,t}$	Unit manufacturing cost of product l at p with Technology t.

$CC_{k,l}$	Unit collection and inspection cost of returned product l at k.
$CR_{r,l}$	Unit recycling cost of product l at r.
$CY_{w,l}$	Unit disposal cost of scrapped product l at w.
$CSM_{s,p,l,m}$	Unit cost of transporting raw material for product l shipped from s to p with m.
$CMD_{p,q,l,m}$	Unit cost of transporting l from p to q using m.
$CDA_{q,c,l,m}$	Unit cost of transporting l from q to c using m.
$CAC_{c,k,l,m}$	Unit cost of transporting l from c to k using m.
$CCR_{k,r,l,m}$	Unit cost of transporting l from k to r using m.
$CRM_{r,p,l,m}$	Unit cost of transporting l from r to p using m.
$CCY_{r,w,l,m}$	Unit cost of transporting l from r to w using m.
$CRS_{r,s,l,m}$	Unit cost of transporting l shipped from r to s using m.
α_l	Return ratio for EOL l.
γ_l	Disposal ratio EOL l.

Parameters related to job creation:

$fj_{p,t}$	Fixed jobs created by p with technology t.
fj_v	Fixed jobs created by facility v, $v \in \{q, k, r, w\}$.
$vo_{p,t}$	Variable jobs at p with technology t.
vo_v	Variable jobs for moving between facility v, $v \in \{q, k, r, w\}$.

Parameters related to CO_2 emission:

$EM_{l,p,t}$	CO_2 emission (kg/unit) for manufacturing product l at p with technology t.
$ED_{q,l}$	CO_2 emission (kg/unit) of handling a l at distribution facility, q.
$ER_{r,l,t}$	CO_2 emission (kg/unit) of recycling a unit l at r.
$EC_{k,l}$	CO_2 emission (kg/unit) in handling a unit of returned product l at collection facility, k.
$EMD_{p,q,l,m}$	CO_2 emission (kg/unit) of moving product l from p to q using m
$EDA_{q,c,l,m}$	CO_2 emission (kg/unit) of moving product l from q to c using m.
$EAC_{c,k,l,m}$	CO_2 emission (kg/unit) of moving returned product l from c to k using m.
$ECR_{k,r,l,m}$	CO_2 emission (kg/unit) for moving l from k to r using m.
$ECY_{k,w,l,m}$	CO_2 emission for moving l from k to w using m.
$ERM_{r,p,l,m}$	CO_2 emission (kg/unit) for moving l from r to p using m.
$ERS_{r,s,l,m}$	CO_2 emission measured in (kg/unit) of l from r to s using m.
C^{cap}	CO_2 emission cap in kg.
ρ^+	Price of selling carbon per unit (kg).
ρ^-	Price of buying CO_2 per unit (kg).

Decision Variables

Binary variables:

ZS_s	1 if s is selected, otherwise, 0
$ZM_{p,t}$	1 if p is open with t, otherwise, 0.
ZD_q	1 if q is open, otherwise, 0.
ZC_k	1 if k is open, otherwise, 0.
ZR_r	1 if r is open, otherwise, 0.

ZY_w	1 if w is open, otherwise, 0.
$ZA_{q,c}$	1 if c is open to q, otherwise, 0.
$ZA_{k,c}$	1 if k is open to c, otherwise, 0.

Continuous variables:

$QBY_{s,l}$	Volume of raw material out sourced by s for product l.
$QSM_{s,p,l,m}$	Volume of raw material for l shipped from s to p using m.
$QM_{p,l,t}$	Volume of l manufactured in p using t.
$QMD_{p,q,l,m}$	Volume of l shipped from p to q using m.
$QDA_{q,c,l,m}$	Volume of product l shipped from q to c using m.
$QAC_{c,k,l,m}$	Volume of l shipped from c to k using m.
$QCR_{k,r,l,m}$	Volume of l shipped from k to r using m.
$QRM_{r,q,l,m}$	Volume of l shipped from r to q using m.
$QRS_{r,s,l,m}$	Volume of l shipped from r to s using m.
$QCY_{k,w,l,m}$	Volume of l shipped from k to w using m.
e^+	Volume of Carbon purchased.
e^-	Volume of carbon sold.