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Research Article

Supply Chain Network Design Integrating Economic, Risk and Energy Sustainability

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Abstract
Supply chains and economic systems have an important role in environmental issues and energy sustainability. Energy is a key factor of all economic systems and has a large environmental impact, therefore its affordable consumption is very important to have a sustainable supply chains and sustainable future. This paper provides a new formulation of supply chain network design by integration of thermodynamic rules about available or useful energy and econometric coefficients and also risk factor in supply chain. The purpose of this integration is to achieve a sustainable supply chain modeling in both fields of available energy and total costs that can guarantees both return of the investments and useful energy in the economic systems. In order to solve the proposed model, augmented ε-constraint method is used and numerical examples are discussed and the results illustrate that the proposed model admitted various progresses in minimizing consumed available energy along with the total costs and risk factor in the proposed model. Also results show that the Gross Domestic Product (GDP) and two of the econometric coefficients generally pointed out as "alpha" and "beta" play a significant role in the amount of consumed available energy and energy sustainability in the supply chain.

Keywords: Supply Chain, Sustainability, Economic, Supply Risk , Augmented ε-constraint Method

Introduction

Human production and economic activities in recent years have been important factors in increasing the use of natural resources and emitting environmental pollutants such as greenhouse gases into the Earth's atmosphere. According to economists, if no action taken to reduce pollutant emissions and reducing energy consumptions, the overall cost and risk of climate change would be at least 5 percent reduction in the global GDP each year (Stern, 2007). Economic growth and population increase have led to increased energy consumption and in the last 30 years, energy demand has risen terribly, so the green activities should be done in order to reduce and control the environmental impact of such increased energy consumption in the

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societies (Yousefi et al. 2019). Also public pressures and some regulations have forced companies to be more cautious about environmental issues in their strategic planning (Mehrshad et al. 2020), therefore developing the sustainable supply chains is an important goal at the present time for every industries.

To achieve this sustainability, we need some measures and tools which could be applicable for the environmental concerns. Embodied exergy is one of such measures that is used in this paper and is a recent tool to evaluate and measure the sustainability of industrial processes (Jawad et al. 2018; Dincer and Rosen, 2012). Embodied exergy compute the primary exergy required to produce a good or a service (Sciubba, 2011). According to thermodynamic rules, exergy is the quality of energy or useful or available energy to measure the maximum useful work during a process (Bosch et al. 2007; Javadi et al. 2019). Or the maximum amount of work that can be extracted from a system is exergy (Apaiah et al. 2006; Chen et al. 2020), so hereafter, whenever is said useful energy or available energy, here is equal to exergy, for easier understanding. So the purpose of using this method in supply chain modelling is to minimize the consumed useful energy or gain the maximum amount of work from a same amount of energy in the system via minimizing the available energy consumed in the supply chain. In result, optimization of this supply chains would profit societies from less useful energy consumption by industries (Jawad et al. 2018). In this paper we have used two econometric coefficients generally mention as "α" and "β" for calculating the available energy equivalents of Labour and Capital according to (Sciubba, 2011), these coefficients have some estimated values and are very different for developed and underdeveloped countries based on the monetary balances of the Society, consumption patterns, life and socio-economic standards of each society.

Supply Chain Network Design includes some decisions like determining the location, number and capacity of the facilities to be considered and it involves the flows of raw materials to finished products to fulfill the customer needs, so it is the most significant strategic decision in supply chain issues (Dehdari Ebrahimi and Momeni Tabar, 2017) and it need to be well optimized specially in designing the sustainable network. In this regard, there are two types of planning in supply chain problems, Single-period and Multi-period. In this paper, the modeling is done for multi-period supply chain because the strategic planning perspectives can be considered for the supply chain, and with a comprehensive and long-term view, price fluctuations, inflations or the value of money and also the existing economic patterns in the society can be better considered in multi-period planning, in order to make more appropriate management decisions.

In the other side, as all members of supply chain are strongly connected to each other, the risk associated with one of the components is quickly transmitted to other members. The risk of supply chain is a function of probability of an event's occurrence. It is better not to wait for an event, but to identify potential risks and plan to respond to them. Merna and Smith (1999) provided a complete list of risk types in the supply chains, one of them is supply risk. The flow of raw materials will most likely to be disrupted due to the suppliers' problems or their unreliability. Supply risk can be due to inability to withstand demand fluctuations, quality problems, inability to overcome the rapid changes and inconsistencies in supply. In this paper, Supply risk is also taken into account as one of the objectives, because suppliers are the starting level of this supply chain and would have important effect to the end process of delivering products to the customers.

This paper provides a sustainable supply chain network design by integration of supply risk and econometric coefficients which calculate the available energy equivalents of Labour and Capital based on the economic conditions of society with four level supply chains in multi-period planning. The purpose is to achieve a low risk sustainable supply chain model which can minimize the consumed useful energy and the total economic cost within whole supply chain processes and finding the effect of economic conditions of GDP and other econometric coefficients on the amount of consumed available energy and energy sustainability in the proposed supply chain.

The rest of this paper is organized as follows: the literature is reviewed in Section 2. Material and methods including the mathematical modelling and the solution approach is provided in Section 3. Computational results are presented in Section 4, and finally conclusion and future works presented in section 5.

Literature Review

One of the strategic problems in supply chain is sustainable supply chain network design, as it involves strategy, logistics, management, environment and operational research (Asgharizadeh et al. 2019). Supply chain network design deals with strategic decisions that have long-lasting and significant impacts on the firm performance and total cost of the chain (Chandra and Grabis, 2007; Farahani et al. 2014). To improve competitive advantages, businesses need to consider both economic costs and social and environmental issues (Massaroni et al. 2015; Munasinghe et al. 2019). Sustainable development is defined in 1987 by World Commission on Environment and Development (WCED) as: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). Based on this definition from WCED, issues also including green supply chain and recycling can also be seen under sustainable issues (Asgharizadeh et al. 2019).

Elkington (1998) introduced the concept of sustainability and it was in (2008) that Carter and Rogers integrated sustainability with supply chain management. And after that, there have been many studies that modelled environmental issues like Bonney and Jaber (2011), Bushuev et al. (2015) and lots of other articles that are published recently with the topic of sustainable supply chain management (Tautenhain ET AL. 2019; Mota ET AL. 2018; Mardani et al. 2020) or green supply chain (Shakeri et al. 2020; Han and Huo, 2020; Mehrshad et al. 2019; Pishvaee et al. 2012) or reverse and closed-loop supply chain (Peng, 2020; Reimann et al. 2019; Amin and Zhang, 2012a; 2012b and Özkır and Başlıgil, 2013).

Asgharizadeh et al. (2019) developed a literature review on the subject of sustainable supply chain network design and one of their result of reviewed models was that 65% of them were single-period (Asgharizadeh et al. 2019). One of the purposes of this paper is to develop the supply chain modeling based on multi-periods to consider the value of money due to the inflationary state of the economy which has received less attention in the previous sustainable supply chain studies.

Sciubba (2011) developed a method named extended exergy accounting for calculating the primary exergy resource equivalent “embodied” in a commodity which are Labour, Capital and Environmental remediation costs and these items were calculated on the basis of two econometric factors named “α” and “β” on the basis of GDP, technology, consumption patterns and socio-economic standards. These econometric coefficients and some other factors like: global monetary circulation in the goal society and labour statistics, population, Average workload, average and global wage in the society, are important for calculating the exergy equivalents mentioned. By using these factors, work-hour exergy equivalent of labour and exergy equivalent of capital were calculated for different developed countries and non-Industrialized Countries that can be used by researchers (sciubba, 2011). Jawad et al. (2018) used these exergy equivalents of sciubba (2011) to improve the sustainability of supply chain in their inventory and ordering system and mentioned that the society would have benefits through this method and less useful energy would be lost while considering this method within their order quantity model.

As mentioned above different studies have been done over sustainability issues in recent years with attention to environmental and green concepts and the main goal of this paper is to assist supply chains to be more cautious about consuming useful energy from environment during the supply chain processes, at the same time helping the managers to have minimized costs and minimized risks. So this modeling would provide a tool for having minimized costs and risks in addition to have less effects on the environment on the context of useful energy consumed in the whole supply chain.

Material and Methods

This paper considers a four-level supply chain model including suppliers, factory, distribution centers, and customers. Model is designed for multi-period condition. The indices, parameters, and decision variables of the sustainable supply chain model are described as follows:

INDICES

s	Index of suppliers; (s= 1, 2, 3, …, S)
m	Index of factories; (m= 1, 2, 3, …, M)
j	Index of distribution centres; (j= 1, 2, 3, …, j)
c	Index of customers; (c = 1, 2, ...,C)
r	Index of raw materials; (r = 1, 2, ..., r)
T	Index of time periods ($\text{t} = 1,2, \dots, \text{T}$)
p	Products ($\text{p} = 1,2, \dots, \text{P}$)

PARAMETERS

d_{sm}	Distance between supplier *s* from factory m
d_{mj}	Distance between factory m and distribution center j
d_{jc}	Distance between distribution center *j* from customer *c*
PC_{rst}	Unit raw material purchasing cost of the raw material *r* supplied by supplier *s* in period *t*
PC_{pmt}	Unit manufacturing cost of product p in factory m in period *t*
TRS_{rsmt}	Unit cost of carrying raw material r from supplier *s* to factory m in period *t*
TRS_{pmjt}	Unit cost of carrying product p from factory m to distribution center *j* in period *t*
TRS_{pjct}	Unit cost of carrying product p from distribution center *j* to customer *c* in period *t*
D_{cpt}	Demand of customer *c* for product p in period *t*
$CAPS_{srt}$	Maximum Supplier *s* Capacity for raw material r in period *t*
$CAPS_{mpt}$	Capacity of factory m for product p in period t
$CAPDC_{jt}$	Maximum distribution centre *j* Capacity in period *t*
b_{rs}	Minimum order amount of raw material r from supplier s
$Risk_{rst}$	Risk of supplying raw material r from supplier s in period t
CR_{rst}	The cost of reducing risk of supplying raw material r from supplier s in period t
FCM_m	Fixed cost of opening factory m
FCT_j	Fixed cost of opening distribution centre j
S_{pmt}	Wage per hour for product p in factory m in period t
$(N_{WH})_{\text{tot}}$	Total number of work-hours performed in the whole system for a specific period of time
α	revenue exclusively obtained from the financial activities
β	primary exergy embodied in the labor
Ex_{in}	Global Exergy (J)
GDP	Gross Domestic Product of goal country

DECISION VARIABLES

b_{rsmt}	Amount of carried raw material r from supplier s to factory m in period *t*

x_t^{Pm}	Number of products produced in the factory m in period *t*
x_{jt}^{PmD}	Number of carried product p from factory m to distribution center *j* in period *t*
x_{jct}^{pDC}	Number of carried product p from distribution center j to customer *c* in period *t*
Y_j	1 if distribution centre j is opened; 0 otherwise
Y_m	1 if factory m is opened; 0 otherwise
θ_{rs}	1 if raw material r is supplied from supplier s ; 0 otherwise
S_{jt}^{Pm}	1 if product p carried from factory m to distribution centre *j* in period *t*; 0 otherwise
S_{jct}^{pDC}	1 if product p carried from distribution centre *j* to customer *c* in period *t*; 0 otherwise

By using the above introduced parameters and variables, the multi-level, multi-product and multi-period model of the sustainable supply chain formulated as below:

Objective Function

The aim of this objective function is to improve the supply chains relation with useful energy consumption in addition to having the economic cost of their production during all of their processes to produce and meeting customers' demand as well. For the exergy parts which include the formula of the primary resource equivalent of the capital and labour, we have used the formula of Sciubba (2011) to calculate the useful energy consumed during our supply chain. So by using the above introduced parameters and variables, the multi-objective, multi-product and multi-period model of the sustainable supply chain formulated as below. All parts of objective function are multiplied to their relevant resource equivalent of the capital or labour whenever they are applicable:

$$\begin{aligned}\text{Min F}_1 = \alpha\beta\frac{\text{Ex}_{\text{in}}}{GDP}\Bigg[&\sum_{r=1}^{r}\sum_{s=1}^{s}\sum_{t=1}^{t} CR_{rst}..Risk_{rst}.\theta_{rs}\sum_{\text{r}=1}^{\text{r}}\sum_{\text{S}=1}^{\text{s}}\sum_{\text{m}=1}^{\text{m}}\sum_{\text{t}=1}^{t}\text{PC}_{\text{rst}}.b_{rsmt}\\ &+\sum_{p=1}^{p}\sum_{m=1}^{m}\sum_{\text{t}=1}^{\text{t}} PC_{\text{pmt}}.\text{x}_{\text{t}}^{\text{Pm}}\\ &+\sum_{\text{r}=1}^{\text{r}}\sum_{\text{s}=1}^{\text{s}}\sum_{\text{m}=1}^{\text{m}}\sum_{t=1}^{t} TRS_{rsmt}.d_{sm}.\text{b}_{\text{rsmt}}\\ &+\sum_{\text{p}=1}^{\text{p}}\sum_{m=1}^{m}\sum_{j=1}^{j}\sum_{\text{t}=1}^{\text{t}} TRS_{pmjt}.d_{mj}\,.\text{x}_{\text{jt}}^{\text{PmD}}+\sum_{\text{j}=1}^{\text{m}}\sum_{\text{k}=1}^{\text{n}}\sum_{\text{t}=1}^{\tau} TRS_{pjct}.\text{d}_{\text{jc}}\,.\text{x}_{\text{jct}}^{\text{pDC}}\\ &+\sum_{m=1}^{m} FCM_M.Y_m+\sum_{j=1}^{j} FCT_j.Y_j\Bigg]+\frac{\alpha\text{Ex}_{\text{in}}}{(\text{N}_{\text{WH}})_{\text{tot}}}\sum_{\text{t}=1}^{\tau}\frac{PC_{\text{pmt}}}{S_{\text{pmt}}}.\text{x}_{\text{t}}^{\text{Pm}}\end{aligned} \quad (1)$$

$$\text{Min F}_{2=}\sum_{r=1}^{r}\sum_{s=1}^{s}\sum_{t=1}^{t}\theta_{rs}.Risk_{rst} \quad (2)$$

The first objective function is consisted of: the cost of risk reduction and risk loss, purchasing raw materials from suppliers, production cost of factories, total transportation cost includes three parts that are functions of distances: the cost of carrying raw materials from suppliers to the factory the cost of transporting products from the factory to distribution centers and the cost of transporting products from distribution centers to customers and Fixed cost of establishing facilities (factories and distribution centers). This multi objective function is consisted of nine parts which the first eight parts are calculated on the basis of their exergy equivalent of monetary and the last part is about the exergy equivalent of working hour of labour for producing in factories according to (Sciubba, 2011). The second objective function minimizes the total supply risk of raw materials from suppliers. Also the relevant constraints are as below:

Subject to:

$$\sum_{j=1}^{j} x_{jct}^{PDC} = D_{cpt} \ \forall \text{ p, c and t} \tag{3}$$

$$\sum_{m=1}^{m} x_{t}^{pm} \leq CAPS_{mpt} \ \forall \text{ m, p} \tag{4}$$

$$\sum_{r=1}^{r} b_{rsmt} \leq CAPS_{srt}.\theta_{rs} \ \forall \text{ s, m and t} \tag{5}$$

$$\sum_{m=1}^{m} b_{rsmt} \geq b_{rs}.\theta_{rs} \ \forall \text{ s, r and t} \tag{6}$$

$$\sum_{j=1}^{j} x_{jt}^{PmD} \leq CAPS_{mpt}.Y_m \ \forall \text{ p, m and t} \tag{7}$$

$$\sum_{p=1}^{p} \sum_{m=1}^{m} x_{jt}^{PmD} \leq CAPDC_{jt.}.Y_j \ \forall \text{ j, t} \tag{8}$$

$$b_{rsmt}, x_{t}^{pm}, x_{jt}^{PmD}, x_{jct}^{pDC} \geq 0 \ \forall \text{ r, i, j, k and t} \tag{9}$$

$$Y_j, Y_m, \theta_{rs}, S_{jt}^{PM}, S_{jct}^{PDC}, \in \{0, 1\} \ \forall \text{ j, m, r, s, c and t} \tag{10}$$

Equation (3) ensures that the demand of each customer for each product in each period should be met from the total amount of products received from distribution centers. Equation (4) and (5) are about production capacity and the suppliers' capacity. Equation (6) says that the total amounts of raw material r which is sent from supplier s to all factories must be more or equal to the minimum order quantity of that supplier. Equation (7) ensures that the sum amounts of each type of product that is sent to all distributors from each factory is less or equal to the capacity of that factory for that type of product. Equation (8) is to ensure that the total amounts of all products sent from all factories to one distribution centre is less or equal to the capacity of that distribution centre. Finally, the last two equations (Equations 9 & 10) are about the range of some variables and parameters.

In order to reach to the minimum amount of the objective functions, ε-constraint method is used due to the proved capability of this method to solve similar problems which had multi-objective functions as (Mohebalizadehgashti et al. 2020; Vafaeenezhad et al. 2019; Hartillo-Hermoso et al. 2020).

The Solution Approach

One of a widely used method for solving Multiple-Objective Mathematical Programming (Ehrgott, 2005) is ε-constraint method. In this method, one of the objective functions will be chosen as a single objective problem, and then other objective functions are considered as constraints with a limited value (Zhou et al. 2018; Jenkins et al. 2019). Although the optimal solution depends on the pre-defined constraint limits. One of the advantages of this method is providing an appropriate picture of whole Pareto-optimal set for decision maker. And the model will be transformed to:

$$\text{Minimize } f_\mu(x) \quad (11)$$

Subject to:

$$\begin{aligned} & f_m(x) \leq \varepsilon_m \; m = 1,2,\ldots,M, \; m \neq \mu; \\ & g_j(x) \geq 0; \; j = 1,2,\ldots,J; \\ & h_k(x) = 0; \; k = 1,2,\ldots,K; \\ & x_i(L) \leq x_i \leq x_i(U) \; I = 1,2,\ldots,n. \end{aligned} \quad (12)$$

The detailed information about ε-constraint method is discussed in (Ehrgott, 2005). Some weaknesses and difficulties like calculating the range of each objective function, achieving the worst solution (Nadir value) and being time consuming in more than two objective functions, resulted in improvements of this method is Augmented ε-constraint method (Mavrotas, 2009; Mavrotas and Florios 2013) which transformed the problem into the following:

$$\max \{ f1(x) + eps \times (s2 + s3 + \cdots + sp)\}, \; eps \in (10-6, 10-3) \quad (13)$$

Subject to:

$$\begin{aligned} & f2(x) - s2 = e2 \\ & f3(x) - s3 = e3 \\ & \ldots \\ & fp(x) - sp = ep, \\ & x \in S \end{aligned} \quad (14)$$

As mentioned in (Nikas et al. 2020), augmented ε-constraint method ensure that just effective Pareto solutions are obtained and all constraints related to the p − 1 objective functions become strict inequalities slack (or surplus) variables are introduced both to the primary objective function and to the constrained ones. One of the other important novelties in augmented ε-constraint method is that, whenever the problem is infeasible, it leads to an early exit from the nested loop of the step increase function and the lower bounds to the constrained objective functions will be set which gradually become stricter. This augmented ε-constraint method is faster model solution and has been used in different studies of supply chain problems in recent years (Razm et al. 2019; Oiu et al. 2019; Sazvar et al. 2018; Mohammadkhani et al. 2018; Musavi and Bozorgi-Amiri 2017).

Further above applications and attentions, augmented ε-constraint method is used in this paper. And first the cost objective function Min F_1 which is in the currency of useful energy is selected due to the higher priority and will be optimized without considering the risk function and the best optimized solution of this objective function will be calculated $(F_1{}^U)$. Now the second objective function which is about risk will be optimized separately for reaching to the best answer $(F_2{}^U)$. After that, the risk objective function will be optimized by considering a constraint $(\text{Cost} = F_1{}^U)$, so the Nadir value of this objective function will be calculated $(F_2{}^N)$. The model of this paper according to augmented ε-constraint will be as below:

$$\text{Min Cost} - eps \times (s2/r2), \; eps \in (10-6, 10-3) \quad (15)$$

S.t:

$$\begin{aligned} & \text{Constraints (1) – (14)} \\ & \text{Risk} + s2 = e2 \end{aligned} \quad (16)$$

In which r is the range obtained from the Payoff table for the objective function of risk and e is different points in this range. By using augmented ε-constraint method, by using different values for points of r, the Pareto sets will be obtained for the problem. For more details about the flowchart of augmented ε-constraint method, please refer to (Mavrotas, 2009; Nikas et al. 2020).

Results and Discussion

In order to show the applicability of the proposed model, problems with simulated data will be solved by CPLEX optimizer algorithm in MATLAB software. The model parameters are obtained using (amin and zhang, 2013; Sciubba, 2011; Sciubba et al. 2008). For preventing to be limited to specific data set and keeping the comprehensiveness of the proposed model, all parameters, are in uniform distribution and data is generated randomly by the software. Below table shows the uniform distribution used to generate the parameters and other data used for solving the problem.

Table 1. Parameters information

Parameter	Amount	Parameter	Amount
d_{sm}	Uniform(300,700)	b_{rs}	Uniform(200,300)
d_{mj}	Uniform(100,200)	$Risk_{rst}$	Uniform(0.5,4)
d_{jc}	Uniform(7,40)	CR_{rst}	Uniform(50000,55000)
PC_{rst}	Uniform(7,8)	FCM_m	Uniform(500000,600000)
PC_{pmt}	Uniform(14,18)	FCT_j	Uniform(300000,4000000)
TRS_{rsmt}	Uniform(0.013,0.016)	α	0.502
TRS_{pmjt}	Uniform(0.013,0.016)	β	1.69
TRS_{pjct}	Uniform(0.013,0.016)	S_{pmt}	18.633
D_{cpt}	Uniform(40000,50000)	$(N_{WH})_{tot}$	2.47*107
$CAPS_{srt}$	Uniform(50000,60000)	Ex_{in}	7.56*1018
$CAPS_{mpt}$	Uniform(80000,95000)	GDP	1.4*1012
$CAPDC_{jt}$	Uniform(100000,115000)	Indexes	S=5, r=3, m=2, p=2, j=4, c=2, t=3

By showing the set of Pareto answers obtained from the augmented ε-constraint method, the trade-offs between the objective functions of risk and cost (which is here on the basis of useful energy), are determined. The Payoff table of example problem is as table 2. So the range of the second objective function of risk is obtained, by dividing this range into five equal points and using augmented ε-constraint method, the Pareto answers will be obtained. Some of the optimized values are showed in below tables. The other optimized values are the same as below tables.

Table 2. Pay off table of example problem

	f1	f2
F1	$F_1{}^U = 15745107.197$	$\mathbf{F_2{}^N}$ =12.971
F2		$\mathbf{F_2{}^U}$ =7.099

Table 3. Objective functions of risk and the cost of consumed available energy

	Cost	Risk
e1	17968957.76	9.274
e2	16173777.45	10.661
e3	15688319.1	12.924
e4	15475445.65	14.683

Table 4. Optimized value for θ_{rs}

s	1				2				3				4				5			
r	e1	e2	e3	e4	e1	e2	e3	e4	e1	e2	e3	e4	e1	e2	e3	e4	e1	e2	e3	e4
1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
2	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	1	1	1
3	1	1	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	1	1

Table 5. Optimized value for S_{jt}^{Pm} for p=1 & t=1

j	1				2				3				4			
m	e1	e2	e3	e4	e1	e2	e3	e4	e1	e2	e3	e4	e1	e2	e3	e4
1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 6. Optimized value for S_{jt}^{Pm} for p=1 & t=2

j	1				2				3				4			
m	e1	e2	e3	e4	e1	e2	e3	e4	e1	e2	e3	e4	e1	e2	e3	e4
1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1
2	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1

Table 7. Optimized value for b_{rsmt} for m=1 & t=1

s	1				2				3			
r	e1	e2	e3	e4	e1	e2	e3	e4	e1	e2	e3	e4
1	18429	0	0	46556	55528	28022	28044	12521	0	0	0	211
2	0	0	0	0	0	33437	13437	0	50494	50590	50590	50590
3	0	0	0	0	0	0	0	0	0	0	0	0
s	4				5							
r	e1	e2	e3	e4	e1	e2	e3	e4				
1	18489	0	0	47556	0	0	0	0				
2	0	0	0	0	0	0	0	0				
3	0	0	0	0	275	0	0	1199				

The sensitivity analysis illustrated in Table 8, shows the relation between mentioned economic coefficients of "alpha" and "beta" and the total cost, so the industrialized and more developed societies have better situation in this regard.

Table 8. Sensitivity analysis by changing the value of "α", "β"[1]

Changing parameters	Cost	Conclusion
$\alpha = 0.502$, $\beta = 1.69$	17968957.76	Default values
$\alpha = 0.364$, $\beta = 0.89$	16484821.75	Less used available energy cost or exergy cost (as were estimated)
$\alpha = 0.773$, $\beta = 1.90$	18760827.19	more consumed available energy cost, more environmental damages

Conclusion

Economic growth doesn't necessarily improve the quality of the environment and has led to increased energy consumption due to the higher consumption of raw materials and natural energies. Energy is one the most important factors of all economics and supply chain systems and has a large environmental impact, therefore its affordable consumption is very important for having sustainability. To achieve the energy sustainability, exergy measure is used as a tool for measuring the sustainability of industrial processes. According to thermodynamic rules, exergy is the quality of energy or useful or available energy. This paper designed a supply chain network by integrating the thermodynamic rules about useful energy and econometric coefficients which calculate the available energy equivalents of Labour and Capital based on

1. Amounts of "α", "β" obtained from Sciubba (2011) which are calculated based on different economic and social items for some selected countries

the economic conditions of society. The purpose is to minimize the consumed useful energy in supply chain processes and reduce the inevitable damages to the environment as much as possible. In this paper, not only total economic costs are optimized but also it is transformed to the available energy costs context. In the other hand, by using the mentioned econometric coefficients with four level supply chains in multi-period planning, a sustainable supply chain network is designed which can minimize the consumed useful energy costs and the total economic cost within mentioned supply chain and based on these objective functions, the optimized values for decision variables of: raw materials, production amount, distributed amounts of products and selecting suppliers, manufacturers and distributors can be obtained for helping managers have better decisions. The relevant formula and econometric coefficients that calculate the mentioned available energy costs equivalents of Labour and Capital are used based on Jawad et al. (2018) and Sciubba (2011). Also supply risk is included in this modeling in order to provide managers to decide under risk situations that is in real world and actually this model made a tradeoff between risk and supply chain economic costs of available energy used within the whole chain. According to this model, revenue obtained from the financial activities and available energy embodied in the labor pointed as "alpha" and "beta" have Direct relation with consumed available energy and GDP has an Inverse relation, the higher the GDP in the community leads to the less available energy costs been used in every supply chain levels. One of the important and interesting points about GDP that is also explained in Jawad et al. (2018) is that, the way people spend their money in their hand, have impact on controlling the used energy. Increasing money in the hands of people leads to a feeling of being richer and as a result tends to spend more. Then there would be more demand and more production and more sales, so the companies order more raw materials for increased production that will at last means more natural energy used and consuming more labor and more capital, so GDP and also value of money needs important attention from governments and societies for having less consumed energy within all industrial processes. Supply chain managers should make the best choices for the number of work-hours performed in the whole system which have a strong relation with the optimized total costs and total consumed available energy based on this model. The benefits of this model in minimizing both economic costs and available energy costs, help managers to decide about their profit along with less destroying the environment and less available energy being used. Another point of this model is to show the relation between the labor and total energy costs, increasing in labor demand will lead to increased used available energy. This paper provides an insight about the potential of the useful energy saving based on some decisions like determining the location, number and capacity of the facilities etc. For future works, the supply chain can be extended more to all layers specially of the closed loop supply chain to make better decisions while having returned items to the chain which may need disposal and lead to more energy lost from the environment, or may return to the supply chain by some approaches. Another suggestion is to include the inflation rate in modeling also to compare different data of "alpha" and "beta" for different industries and different countries to compare the results.

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