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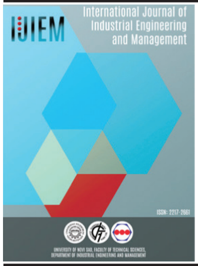

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A two-stage sustainable production-inventory model with carbon credit demand

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ABSTRACT

Carbon credit is known as one of the most effective market-based tools to control the generation of carbon emissions. In order to mitigate carbon intensity and enhance energy efficiency within product systems, the utilization of carbon credits emerges as a valuable tool for companies striving to achieve ambitious targets in reducing greenhouse gas (GHGs) emissions. This study aims to investigate the impact of employing carbon credits in contrast to traditional inventory models. To overcome these shortcomings, a two-stage inventory model to design a green supply chain in a carbon trading environment is presented in this paper. The model solves a pricing problem and determines the optimal production run time of component and the carbon credit price. The presented model is employed in a real-world case study, and the numerical results are meticulously analysed and interpreted. The results of the model showed that there exists an optimal solution or optimizer. We have presented an algorithm to compute the value of an optimal solution. After the computation of an algorithm, there was more than sufficient evidence to show the beneficial effects of Taiwan bike manufacturer's model. The findings of sensitivity analysis also have implications for this proposed model. As an illustration, the outcomes achieved through pollution prevention can be juxtaposed with those derived from non-investment operations, considering various parameter settings. This comparison aids in identifying an opportune moment for implementing pollution prevention measures.

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1. Introduction

This paper discusses the role of emission trading systems in determining carbon credit prices through international carbon markets. Many companies and governments are finding it critical to know how to calculate carbon credits and price them. Carbon credits and offsets are vital components of global emissions trading strategies to lower emissions and reach net zero. Within this framework, businesses have the option to receive complimentary carbon allowances from the government and engage in buying or selling carbon allowances in emissions trading markets as needed [1]-[2]. While the emissions trading mechanism has the potential to encourage remanufacturing and other environmentally friendly production activities under various carbon allowance allocation rules, both academic studies and practical evidence indicate that constrained carbon credits consistently impede manufacturers' profits [3], [4],and [5] developed a two-period production decision model for

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a monopolistic manufacturer to tackle these challenges. In the initial period, the manufacturer exclusively produces new products, whereas in the second period, both new and remanufactured products are concurrently manufactured, taking into account capital and carbon emissions constraints. Early theorization of economic production quantity (EPQ) model with the constant demand can be traced back to [6]. Odanaka [7] considered a generalization of deterministic inventory problem with non-constant demand. However, in many real production systems, demand pattern can be price-dependent demand [8]-[12]; stock-dependent demand [13]-[14]; freshness-dependent demand [15]; age-dependent demand [16]-[17]; quality-dependent demand [18]; time-dependent demand [19]-[20]. Dye and Yang [21] considered issues of sustainability in the context of joint trade credit and inventory management in which the demand depends on the length of the credit period offered by the retailer to its customers. Taleizadeh et al. [22] examined an economic order quantity (EOQ) model by integrating environmental considerations within the context of partial trade credit and partial backordering. Rezaee et al. [23] introduced a two-stage stochastic programming model for designing a sustainable supply chain within the framework of a carbon trading environment. Olschewski and Benítez [24] determined the impact of a joint production of timber and carbon sequestration on the optimal rotation of a fast-growing species in north-western ecuador. Ruidas et al. [25] developed an EPQ model with variable production rate and it varies with the demand rate. Shortages are allowed and it is backlogged fully. The impacts of climate change on different sectors of society are interrelated. A central goal of promoting green growth is to enhance the efficiency of production processes in order to reduce emissions. The key factor behind this global warming is emission of greenhouse gases (GHGs), like carbon dioxide (CO2), ozone (O3), methane (CH4), nitrous oxide (N2O), etc. Among these GHGs, CO2 is the most dangerous and prevalent GHGs considering its role in global warming. A greenhouse gas (GHGs) inventory reflects the GHGs impact of a country's economic activities and its domestic carbon footprint. Di and Yang [26] quantified and compared the greenhouse gas (GHGs) emissions of production-inventory-transportation (PIT) supply chains enabled by both traditional manufacturing (TM) and additive manufacturing (AM) technologies. Thus, government regulations concerning the environment require companies to decrease pollutant emissions to specified levels. Numerous industries are not only aiming to meet these standards but are also actively striving to emerge as leaders in environmental consciousness. There is substantial evidence indicating that consumers are increasingly inclined to support businesses that demonstrate a genuine commitment to environmental responsibility, exemplified by their pursuit of green industrial development. Ruidas et al. [27] investigated a production inventory model that takes into account two similar high-tech products. The decision variables in this study encompass selling prices, production rates, and production run times for both products. Meanwhile, Ruidas et al. [28] examined the impacts of a concurrent investment in green innovation (GI) and emission reduction technologies (ERTs) within a green production inventory model. This model considers interval-valued parameters for various inventory cost components and carbon emission factors. Xu and Lin [29] explored the contribution of the high-tech industry in mitigating China's CO2 emissions. Zdraveva et al. [30] highlighted the lessons learned and good practices regarding the greenhouse inventory system in the Republic of Macedonia. Ramandi and Bafruei [31] aimed to diminish greenhouse gas (GHGs) emissions in a two-echelon supply chain (SC) with a single supplier and retailer, taking into account government policies. Ruidas et al. [32] aimed at formulating an imperfect production inventory model considering diverse carbon emission regulatory policies, with the carbon emission parameters modeled as interval numbers. Shahbazi et al. [33] studied the effects of power generation emissions on local criteria air contaminants and greenhouse gas emissions. Various approaches to GHGs are discussed in [34], [35], [36]. As this review has shown, most inventory research on the extent to which demand patterns is beneficial to EPQ/EOQ model has been undertaken. It differs from previous studies, however, we estimate that demand for carbon credit price. Few studies have been done on the effect of six greenhouse gases on production system. In doing so, it aims to enhance our expanding comprehension of the greenhouse effect and carbon credits within the EPQ model. Rebate and carbon credit price pose a common issue in inventory management, particularly prevalent in manufacturing factories. To address this challenge, it is essential to adjust not only production planning but also return activities. The contributions of this paper are a better understanding of carbon credit price, six greenhouse gas and investment policy in the carbon market. Other related studies on this topic are listed in Table 1.

Table 1. The major issues compared some present EPQ models with the present paper

	Major issue								
References	Stage	CPD	PD	SD	FD	AD	QD	TD	Other consideration(s)
Chen and Hu [8]	SS		V						Joint inventory and pricing model
Guria et al. [9]	SS		V						Inflation/Shortages/Delay in payment
Yang et al. [10]	SS		V						Cash discount/trade credit
Panda et al. [11]	SS		V						Corporate social responsibility/ Nash bargaining
Mishra et al. [12]	SS		V						Non-instantaneous/Environmental emissions reduction/Sustainable
Saha & Goyal [13]	MS			V					Three unlike coordinating contracts/ Bargain theory
Pal et al. [14]	MS			V					100% screening process/rework
Chen et al.[15]	SS				V				Expiration date/Shelf space
Avinadav et al. [16]	SS					V			Shelf-life duration/Substitute goods/ Price elasticity
Dobson et al.[17]	SS					V			Grocery industry/Consumer behaviour
Glock et al.[18]	SS						V		Indicator/Environment
San-José et al.[19]	SS							V	Time-power function/Demand pattern
Dye [20]	SS		V						Advertising effort/Goodwill/ Psychic stock/Freshness index
Dye & Yang [21]	SS	V							Environmental regulation/ Trade credit/ Default risk/Carbon emissions
The present paper	SS	V							Carbon credit price/GHGs

Note: single stage (SS), multi-stage (MS), carbon price demand (CPD), price-dependent demand (PD), stock-dependent demand (SD), freshness-dependent demand (FD), age-dependent demand (AD), quality-dependent demand (QD), time-dependent demand (TD)

The following three issues are often posed by manufacturers as key points of interest:

(1) What is the optimal carbon credit price to reduce emissions?

(2) When is the optimal production run time to run the production of a component?

(3) What is the optimal investment policy?

The reset of this paper is as follows. The remainder of the paper is organized as follows. Notation and assumptions are listed in Section 2. Mathematical formulations and theoretical results are presented in Section 3. An application example, numerical example and sensitivity analysis are presented in Section 4. Discussions are then presented in Section 5. Conclusions and suggestions for further research are provided in Section 6.

2. Notation and assumptions

In this paper, from among natation and assumptions in making complex decisions and two-stage production models for the greenhouse effect and carbon credits by similarity calculus approach has been dealt with. Therefore, the aim of this paper is to extend Su et al.[37] model concerning the GHGs problems with real data.

2.1 System parameters:

k = set-up cost.

S_p = selling price per unit item.

n = number of required components for an end product.

p_i = production rate of component i in units per unit time, where i =1, 2,..., n and $p_1 > p_2 > ... > p_n$.

λ = assembly rate of WIP (Work-In-Process) in units per unit time.

F_g = yearly investment expenditure for carbon emission reduction per cycle, including allocations for devices like air purifiers, washing towers, or filtration equipment.

V_g = variable cost to reduce the emission of pol lutants per unit item, such as power or material for equipment.

h_i = holding cost of component i per unit time, where i = 1, 2,..., n.

t_{id} = time interval before the depletion of the component inventory i, $t_{id} \geq 0$, where $i = 1, 2,..., n$.
T = length of cycle, $T \geq 0$.
H_i = maximum inventory level of component i, where $i = 1, 2,..., n$.

2.2 Decision variables:

t_i = production run time of component i, $t_i \geq 0$, where $i = 1, 2,..., n$.
s = unit carbon credit price, $s \geq 0$.
r = investment to reduce the emission of pollutants, where r is binary variable,

$$r = \begin{cases} 1, & \text{invest} \\ 0, & \text{no invest} \end{cases}.$$

This paper is based on the following assumptions:

(a) To avoid the starvation, it is necessary that the minimum production rate in Stage 1, the assembly rate in Stage 2, and demand rate satisfy the following condition: $p_n > \lambda > D$.

(b) In adapting to real-world scenarios, we are directed to synchronize with a known but non-constant demand rate. The demand exhibits variability, influenced not only by external factors but also by price dependence. Building on the demand pattern proposed by [38], it is affected by factors such as the selling price, social donation amount, and investment in green industrial development. Model formulation was facilitated by assuming that demand is a simple linear function, $D = a - bs_p + \delta s + wr$, where $a > 0$ is the market potential, b is the elasticity factor of selling price, δ is the elasticity factor of carbon emission, and w is the elasticity factor of investment to reduce the emission of pollutants.

(c) The transition of a company into a green industrial entity entails reducing emissions to a specified (standard) level with the objective of enhancing purchasing intent by bolstering corporate image. This necessitates investment, encompassing fixed costs for equipment per cycle F_g (e.g., apportion charges per cycle for air purifiers, washing towers, or filtration) and variable costs per unit time of operations V_g (e.g., materials, water, and energy). Typically, such investments are allocated based on their respective contributions to the overall positive effects. One of purposes of this paper is to determine whether the investment in green industrial development is advantageous or not. If this investment is benefit, the value of r will be 1. Otherwise, $r = 0$. Therefore, in this study, we designated r as a binary decision variable and assessed the total profit per unit time under $r = 0$ and $r = 1$ to determine the feasibility and advantage of investing in green industrial development.

(d) The production cycle repeats infinitely.

3. Model formulation

The purpose of the paper here was to explore carbon credit price on investment issue through data analysis of an inventory model.

R1. According to [37] and assumption 1, to ascertain the quantity of components needed to meet the end product yield, the total demand remains constant within a given cycle; i.e. $p_1t_1 = p_2t_2 = ... = p_it_i... = p_nt_n = DT$ then we have

$$t_i = \frac{p_n t_n}{p_i}, \tag{1}$$

and

$$T = \frac{p_n t_n}{D}, \tag{2}$$

where $i = 1,2,...,n$.

The relationship among inventory level of WIP and components in the whole production control system is illustrated in the Figure 1. A concept statement can be used to pitch an idea how to set up an assembly to use these WIP in a two-stage assembly production system.

R2. The maximum inventory level of component i can be expressed as

$$H_i = (p_i - \lambda)t_i = \lambda t_{id} \tag{3}$$

Upon rearranging Eq. (3), we derive the following:

$$\begin{aligned} t_{id} &= \frac{(p_i - \lambda)t_i}{\lambda}, \\ &= \frac{(p_i - \lambda)p_n t_n}{\lambda p_i}, \qquad \text{(from Eq. (1))} \end{aligned} \tag{4}$$

where $i = 1,2,...,n$.

Based on the above results, it order to quantify the system efficiency, we also need to measure the total profit per cycle as follows:

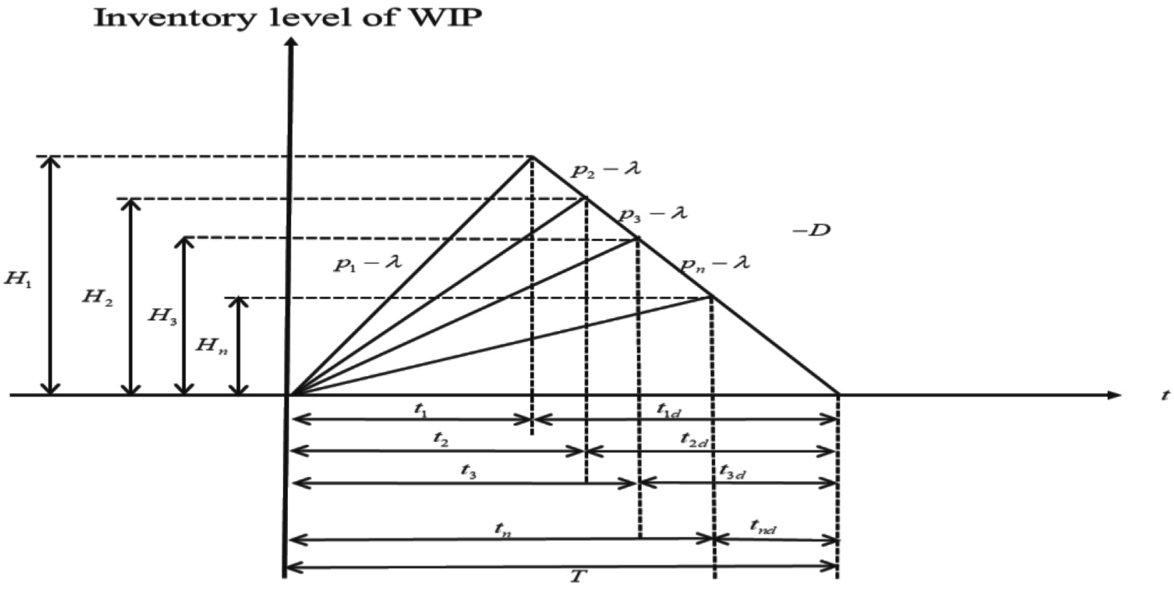

Figure 1. Graph of inventory levels for WIP

(a) Sales revenue (represented by SR): The sales revenue equals the effective operating revenue, $s_p - s$, multiplied by the total demand, DT, as illustrated below:

$$\begin{aligned} SR &= \left(s_p - s\right) DT \\ &= \left(s_p - s\right) p_n t_n. \quad \text{(from Eq. (2))} \end{aligned} \tag{5}$$

(b) Set-up cost (represented by SC): The set-up cost is a fixed value, k, encompassing expenses related to tool or mold changes, material or component relocation, and initial output inspection.

(c) Holding cost of all components (represented by HC_s): Similarly, the total holding cost for n components per cycle is computed as follows:

$$\begin{aligned} HC_s &= \sum_{i=1}^{n} \frac{h_i H_i \left(t_i + t_{id}\right)}{2} \\ &= \frac{p_n^2 t_n^2}{2} \left[\sum_{i=1}^{n} h_i \left(\frac{1}{\lambda} - \frac{1}{p_i} \right) \right]. \\ &\qquad \text{(from Eqs. (1), (3), and (4))} \end{aligned} \tag{6}$$

(d) Production costs (denoted by $CO_2 + NO_x + SO_x$): Carbon emissions from production are modeled following the methodology of [40]. It is defined by the average energy consumption of production per ton (e_p), the emission standard for energy generation (E_g), and the cost of emitting carbon per ton (c_1), denoted as $c_{1e} = e_p E_g c_1$. The cost associated with emitting NO_x is determined by the quantity of NO_x emissions (c_2), resulting in c_{2e}, $c_{2e} = NO_x c_2$. The SO_x emission cost function is constructed in a similar manner to the NO_x function as $c_{3e} = SO_x c_3$; The environmental ergonomic costs associated with NO_x and SO_x are derived from the model proposed by [41], wherein costs are determined by constraining or limiting the volume of emissions. However, their equation has been adjusted to align with the specific needs of this study. These costs are correlated with the quantity produced per cycle, equivalent to the demand rate. Consequently, the production cost function is expressed as:

$$PC = \left(c_{1e} + c_{2e} + c_{3e}\right) DT. \tag{7}$$

(e) Investment to reduce the emission of pollutants (denoted by IC): The investment cost is the aggregate of the fixed cost, F_g, and the variable cost, $V_g DT$, multiplied by a binary variable, r, expressed as:

$$\begin{aligned} IC &= r\left(F_g + V_g DT\right) \\ &= r\left(F_g + V_g p_n t_n\right), \quad \textit{(from R1)} \end{aligned} \tag{8}$$

Considering the concept of life-cycle, there will be a logistic cost value for each period (e.g. year). Overall, the total profit per unit time can be obtained as follows:

$$AP(s,t_n,r)=\frac{1}{T}\left\{SR-SC-PC-HC_s-IC\right\}$$
$$=\frac{D}{p_nt_n}\Big[\left(s_p-s\right)-k-\left(c_{1e}+c_{2e}+c_{3e}\right)p_nt_n\Big]$$
$$-\frac{p_n^2t_n^2}{2}\left[\sum_{i=1}^{n}h_i\left(\frac{1}{\lambda}-\frac{1}{p_i}\right)\right]-r\left(F_g+V_gp_nt_n\right)\Bigg]. \tag{9}$$

First, for given r, we take the first-order partial derivatives of the total profit per unit time for given value of r (denoted by $AP(s,t_n|r)$) with respect to s and t_n, we obtain

$$\frac{\partial AP(s,t_n|r)}{\partial s}=\frac{1}{p_nt_n}\Big\{\Big[\delta s_p-k-\left(c_{1e}+c_{2e}+c_{3e}\right)p_nt_n\Big]$$
$$-\frac{p_n^2t_n^2}{2}\delta\left[\sum_{i=1}^{n}h_i\left(\frac{1}{\lambda}-\frac{1}{p_i}\right)\right]-\delta r\left(F_g+V_gp_nt_n\right)-a+bs_p-2\delta s-wr\Bigg]\Bigg\}, \tag{10}$$

and

$$\frac{\partial AP(s,t_n|r)}{\partial t_n}=\frac{D}{p_nt_n^2}\Big\{\Big[-\left(s_p-s\right)+k\Big]$$
$$-\frac{p_n^2t_n^2}{2}\left[\sum_{i=1}^{n}h_i\left(\frac{1}{\lambda}-\frac{1}{p_i}\right)\right]+rF_g-rV_gp_nt_n\Big\}. \tag{11}$$

By solving $\partial AP(s,t_n|r)/\partial s=0$ and $\partial AP(s,t_n|r)/\partial t_n=0$, we can be obtained as follows:

$$s=\frac{1}{2\delta}\Big[\delta s_p-k-\left(c_{1e}+c_{2e}+c_{3e}\right)p_nt_n\Big]$$
$$-\frac{p_n^2t_n^2}{2}\delta\left[\sum_{i=1}^{n}h_i\left(\frac{1}{\lambda}-\frac{1}{p_i}\right)\right]\Bigg] \tag{12}$$
$$-\delta r\left(F_g+V_gp_nt_n\right)-a+bs_p-2\delta-wr\Big\},$$

and

$$t_n=\sqrt{\frac{2\left\{k+rF_g-\left(s_p-s\right)-rV_gp_nt_n\right\}}{\left[\sum_{i=1}^{n}h_i\left(\frac{1}{\lambda}-\frac{1}{p_i}\right)\right]p_n^2}}. \tag{13}$$

Based on Eq. (13), the value of s^* is an increasing function of $t_n^*\in[0,\infty)$. Now, we designate the right-hand side of Eq. (14) as:

$$R(t_n^*)=\frac{1}{2\delta}\Big\{\Big[\delta s_p-k-\left(c_{1e}+c_{2e}+c_{3e}\right)p_nt_n\Big]-\frac{p_n^2t_n^2}{2}\delta\left[\sum_{i=1}^{n}h_i\left(\frac{1}{\lambda}-\frac{1}{p_i}\right)\right]\Bigg]$$
$$-\delta r\left(F_g+V_gp_nt_n\right)-a+bs_p-2\delta-wr\Big\}. \tag{14}$$

Then, we obtain the following results:

Lemma 1:

(i) *If* $R(t_n^*)>0$, *then* $AP(s,t_n|r)$ *is concave, and reaches its maximum value at the point* (s^*, t_n^*) *shown as in Eqs. (12) and (13) not only exists but also is unique.*

(ii) *If* $R(t_n^*)\le 0$, *then* $AP(s,t_n|r)$ *reaches its maximum value at the point* (t_n^*, 0), *where* t_n^* *is shown as in Eq. (14).*

3.1 Algorithm

Step 1. Let $r=\tilde{r}_j=\begin{cases}0, & if\ j=0\\ 1, & if\ j=1\end{cases}$.

Step 2. Start with $\tau=0$ and $s_{j,\tau}=0$.

Step 3. Put $s=s_{j,\tau}$ into Eq. (13) to obtain the corresponding value of t_n, i.e., $\tilde{t}_{nj}$, and then from Eq. (14) to calculate $R(\tilde{t}_{nj})$.

Step 4. If $R(\tilde{t}_{nj})\ge 0$, put $\tilde{t}_{nj}$ into Eq. (12) to obtain the corresponding value of s, i.e., $s_{j,\tau+1}$. Otherwise, let $\tilde{s}_j=0$.

Step 5. If the difference between $s_{j,\tau}$ and $s_{j,\tau+1}$ is sufficiently small, set $\tilde{s}_j=s_{j,\tau+1}$. Otherwise, set $s_{j,\tau+1}=s_{j,\tau}+\varepsilon$, where ε is any small positive number, and set $\tau=\tau+1$; then, go back to Step 3.

Step 6. Substitute $t_n=\tilde{t}_{nj}$ and $s=\tilde{s}_j$ into Eq. (9) to calculate the value of $AP(\tilde{s}_j,\tilde{t}_{nj},\tilde{r}_j)$.

Step 7. If $AP(\tilde{s}_0,\tilde{t}_{n0},\tilde{r}_0)<AP(\tilde{s}_1,\tilde{t}_{n1},\tilde{r}_1)$, then $(s^*,t_n^*,r^*)=(\tilde{s}_1,\tilde{t}_{n1},\tilde{r}_1)$ is the optimal solution. Otherwise, $(s^*,t_n^*,r^*)=(\tilde{s}_0,\tilde{t}_{n0},\tilde{r}_0)$.

Step 8. Substitute s^*, t_n^* and r^* into Eqs. (1), (2) and (9) to calculate the values of $t_1^*, t_2^*,\ldots, t_{n-1}^*, T^*$, and $AP(s^*,t_n^*,r^*)$.

4. Practical case

The paper suggests a case study to evaluate the effectiveness of the model in a two-stage production system. A numerical example of this case was employed to validate our analytical results, and sensitivity analysis was conducted to investigate trends in optimal policies, providing managerial insights for the bike manufacturer. Figure 2. served as a comprehensive overview of the fundamental bike manufacturing process, providing a foundation for discussion on various elements such as wrought aluminum alloys, drilling, broach, milling machine, WIP, drill press and tapping. A process flow diagram was generated using Microsoft Visio depicting the process of a bike manufacturing process. A study was undertaken to

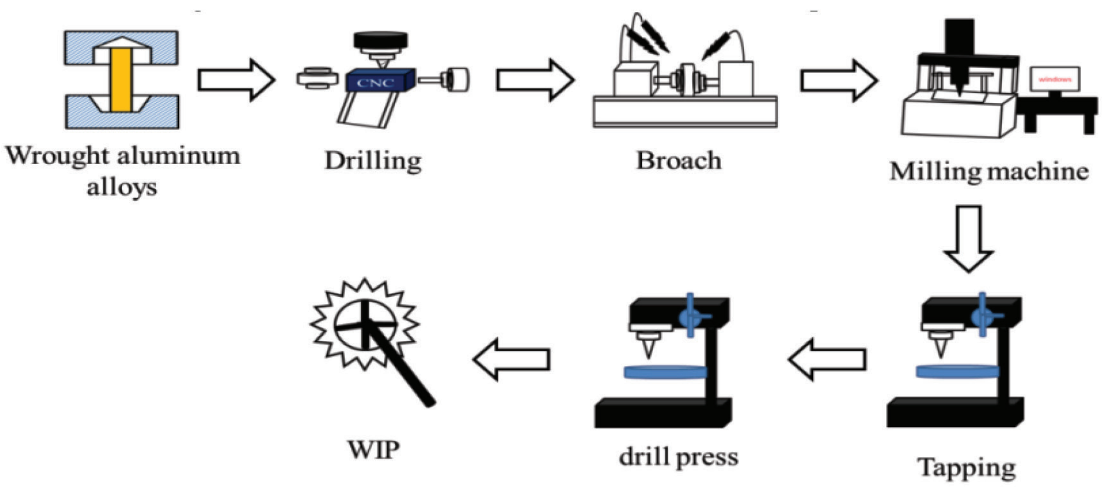

Figure 2. Dual-phase manufacturing system for bike components production

assess the impact of carbon dioxide (CO_2), nitrous oxide (NO_x), and sulfur dioxide (SO_2) on components production. Carbon emissions were evaluated from various processes linked to a CNC-based machining system. Carbon credits are intended to assist bike manufacturers in reducing emissions, yet there is a variation in pricing, with each credit representing the offset of one tonne of CO_2. Bike manufacturers can offset their unavoidable emissions by purchasing carbon credits from certified activities that contribute to community development, protect ecosystems, or implement efficient technologies to reduce or eliminate emissions from the atmosphere.

4.1 Numerical example

To illustrate the solution procedure, we consider an inventory system with the following data:

- *Demand function: a=300, b=0.05, δ=0.1, w=20, s_p=\$4000/per unit .*
- *Component 1 process: p_1=1000/per unit time, h_1=\$0.1/per unit/per unit time.*
- *Component 2 process: p_2=900/per unit time, h_2=\$0.2/per unit/per unit time.*
- *Component 3 process: p_3=800/per unit time, h_3=\$0.3/per unit/per unit time.*
- *Other costs: k=\$30/per cycle, s_p=\$4000/per unit, c_1=\$60/per unit time, c_2=\$15/per unit time, c_3=\$5/per unit time, F_g=\$500/per cycle, V_g=\$2/per unit, e_p=17, E_g=0.005, NO=1.12, SO=1.9, λ=0.01.*

Applying the proposed algorithm in section 3.1, the following shows that optimal solution is s^*=262.28, t_3^*=0.00438 , r^*=1, and $AP(s^*, t_n^*, r^*)$=\$117288. Examining Table 2 reveals a significant increase in the proportion's investment revenue parameters F_g, with growth percentages of 5.16% (+50%), 42.69% (+25%), 134.7% (-25%), and 152.8% (-50%). Considering these findings, it is advisable for the company to proceed with investments in pollution prevention. In the industrial sector, examples of reducing pollution practices include: modifying a production process to produce less waste, implementing water and energy conservation practices.

4.2 Sensitivity analysis

The numerical illustration provided in Section 4.1 served as a means to evaluate the impact of alterations to system parameters (k, s_p, c_1, c_2, c_3, δ, w, F_g, V_g, h_1, h_2, h_3, p_1, p_2, p_3, e_p, E_g, NO_x and SO_x) on the values of s^*, t_n^*, r^*, and $AP(s^*, t_n^*, r^*)$. Table 2 shows the optimal for each parameter by +50%, +25%, −25%, or −50% (i.e., the others parameters were left unchanged). From Table 2, we can draw the following conclusions:

1. Total profit exhibits moderate sensitivity to the parameter e_p, demonstrating a proportional relationship with the parameter e_p. This suggests that decreasing energy consumption and chemical inputs would contribute to profit optimization.
2. Once more, the profit function demonstrates high sensitivity to E_g, and considerable sensitivity to both SO_x and NO_x. Conversely, the total profit function displays minimal sensitivity to these parameters c_1, c_2, c_3, h_1, h_2, h_3, p_1, p_2 and p_3. It implies that the investments of pollution prevention help organizations reduce their greenhouse gas (GHGs) emissions.

3. Our findings indicate that augmenting w is likely the most effective strategy for enhancing $AP(s^*, t_n^*, r^*)$. Consequently, it may prompt the company to escalate investment in environmental pollution control by increasing the investment coefficient.
4. In terms of holding cost parameters, decreasing the values of parameters SO_x, and NO_x, led to a corresponding increase in s^*. This is an indication that carbon credit pricing provides incentives for company to reduce emission of sulphur dioxide, nitrogen dioxide, while also mobilising company revenue.
5. When r =1, the manufacturer may earn profit than r =0. It implies that the carbon credit invested in environmental pollution control (r =1), the more obvious the effect of environmental pollution control.
6. When r =1, the manufacturers will invest in environmental pollution control, they can purchase higher carbon credits price to offset their carbon emissions. It implies that carbon offsetting can help individuals and organisations meet emissions reduction targets, such as those set by governments or industry associations.

5. Discussion

Many nations, the United States included, implement a variety of greenhouse gas mitigation policies that offer subsidies or impose restrictions, often targeting specific technologies or sectors. In a study by Petersen and Solberg [34], the application of glulam beams was evaluated at a newly constructed airport near Oslo, comparing it to an alternative steel solution. The objectives encompass: (1) conducting a thorough evaluation of greenhouse gas (GHGs) emissions and energy consumption across the entire life cycle of glulam and steel, (2) quantifying the reduced GHGs emissions and assessing the cost implications associated with the substitution, and (3) analyzing the pivotal factors influencing the outcomes. Ruidas et al. [32] formulated an imperfect production inventory model within the framework of diverse carbon emission regulatory policies, considering interval numbers for the various carbon emission parameters. Shahbazi et al. [39] examined the impact of power generation emissions on local criteria air contaminants and greenhouse gas emissions. The study revealed that power plants using high-sulfur heavy oil for electricity generation contributed 56% to NO_x emissions and 97% to SO_x emissions, forming a substantial portion of the overall emissions. A goal of this paper is to identify the investment of pollution prevention in a two-stage production system. Prior to energy consumption parameter estimation, determining the effect of cost parameter on the energy consumption is crucial. Figure 3 presents the cost of emitting carbon per ton (c_1), the amount of NO_x emission (c_2), the SO_x emission cost function (c_3), average energy consumption of production per ton (e_p), and energy generation standard emission (E_g). A possible explanation for these parameters is that the cap-and-trade program is a key element of bike manufacturer's strategy to reduce greenhouse gas emissions.

To summarize the salient features of Figure 3, several findings are of interest.

1. In terms of investment, many investors aim to direct their investment funds toward companies and opportunities actively involved in reducing greenhouse gas emissions. The analysis indicates that when an investor considers investing in pollution prevention (r=1), the factors influencing total profit per unit time are the cost of emitting carbon per ton (c_1), the amount of NO_x emission (c_2), the average energy consumption of production per ton (e_p), and the activation of energy generation standard emission (E_g). Among these, the cost of emitting carbon per ton has a more substantial impact on the overall profit.
2. Investment exposure frequently focuses on initiatives related to the conservation of natural resources, pollution reduction, and business practices that yield an overall positive impact on the environment.
3. The Environmental, Social, and Governance (ESG) proposition is intricately connected to cash flow through five crucial mechanisms: (1) fostering top-line growth, (2) cutting down on costs, (3) mitigating regulatory and legal interventions, (4) enhancing employee productivity, and (5) optimizing investment and capital expenditures.
4. Higher credit prices will increase manufacturer's willingness to implement pollution prevention.

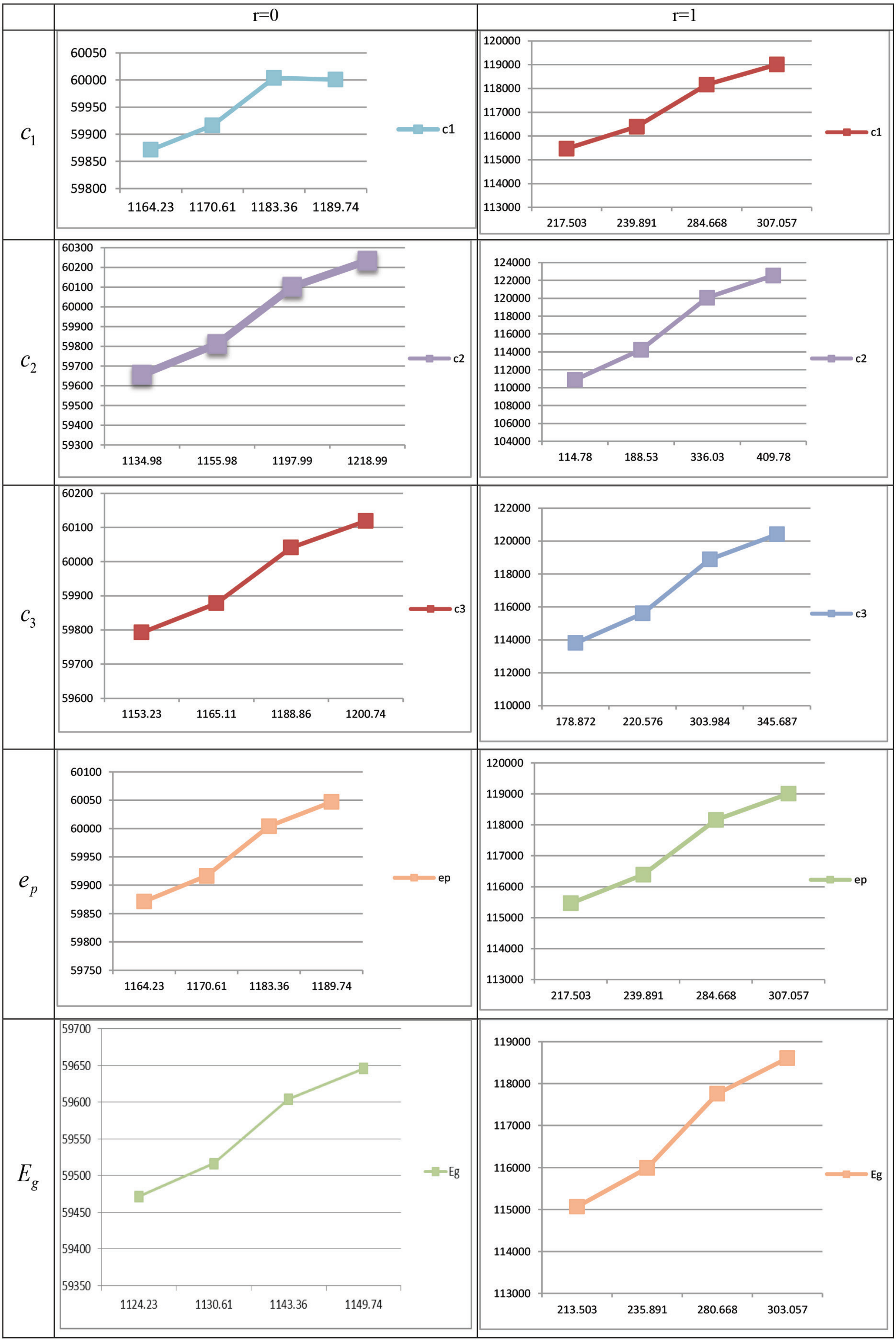

Figure 3. Manufacturer's profit from carbon pricing, selected parameters

6. Conclusion

In this paper, we firstly derive the optimal production decisions with carbon credit price in analysis of cost-effective pollution prevention measures. By analysing the carbon credit setting with sell price, this paper has some findings:

1. The optimal investment decision when the fixed cost is larger than the variable cost ($F_g > V_g p_n t_n$).

2. To meet a building's carbon limit, bike manufacturer can lower carbon directly through lower emissions coefficients (δ), and higher investment ratio (w).

The present paper enhances the previous studies' findings by providing a much more detailed examination of carbon credit. Then, we can also obtain some managerial insights.

1. Since the manufacturer's profit may be increasing in the carbon price, he can use revenue sharing contract to cooperate with retailer to increase his profit.

2. Using green technology may increase the total carbon emission.

While this production model serves as a professional practice model, it is not without limitations. Initially, our analysis focuses on a supply chain comprising a solitary manufacturer and a single retailer within a two-stage production model. A valuable extension of our research would involve incorporating a multi-stage production model. Additionally, our consideration is confined to single-period production decisions and credit price setting. A promising avenue for future exploration is the examination of the manufacturer's multi-period operational decisions and credit price allocation across different periods. Lastly, the incorporation of green technology by the manufacturer under cap-and-trade regulation is a potential area for further investigation.

Table 2. Influence of proposed model parameters

Parameter		$r = 0$			$r = 1$		
		s^*	t_n^*	$AP(s^*, t_n^*, r^*)$	s^*	t_n^*	$AP(s^*, t_n^*, r^*)$
k	45	1059.2	0.00153	47762.7	1168.707	0.00447	110086
	37.5	1117.2	0.001397	52992.0	1215.466	0.00443	113687
	22.5	1239.27	0.00108	70017.6	1309.15	0.00434	120891
	15	1305.47	0.00088	86655.9	1356.079	0.00429	124497
s_p	6000	2676.98	0.00125	87063.5	2762.28	0.00438	184945
	5000	1926.98	0.00125	72889.5	2012.28	0.00438	149361
	3000	426.72	0.00125	48276.5	1187.72	0.00438	88724.8
	2000	323.01	0.00125	37837.6	1137.72	0.00438	63672.1
c_1	90	1164.23	0.00125	59871.4	1217.503	0.00438	115465
	75	1170.61	0.00125	59916.3	1239.891	0.00438	116390
	45	1183.36	0.00125	60004.0	1284.668	0.00438	118159
	30	1189.74	0.00125	60000.7	1307.057	0.00438	119004
c_2	22.5	1134.98	0.00125	59656.0	2114.78	0.00438	110874
	18.75	1155.98	0.00125	59811.2	2188.53	0.00438	114227
	11.25	1197.99	0.00125	60100.9	2336.03	0.00438	120057
	7.5	1218.99	0.00125	60233.5	2409.78	0.00438	122537
c_3	7.5	1153.23	0.00125	59792.2	1178.872	0.00438	113805
	6.25	1165.11	0.00125	59877.6	1220.576	0.00438	115593
	3.75	1188.86	0.00125	60040.9	1303.984	0.00438	118889
	2.5	1200.74	0.00125	60118.7	1345.687	0.00438	120398
δ	0.15	1445.99	0.00125	78635.5	1696.069	0.00439	151589
	0.125	1338.39	0.00125	69255.7	1522.554	0.00439	134624
	0.075	907.981	0.00125	50853.6	1171.511	0.00439	99331.1
	0.05	369.974	0.00125	42246.6	1103.091	0.00439	80002.3
w	30	1176.98	0.00125	59960.5	1212.281	0.00439	123422
	25	1176.98	00125	59960.5	1237.282	0.00439	120337
	15	1176.99	0.00125	59960.5	1287.283	0.00439	114274
	10	1176.99	0.00125	59960.5	1312.281	0.00439	111294

		$r = 0$			$r = 1$		
Parameter		s^*	t_n^*	$AP(s^*, t_n^*, r^*)$	s^*	t_n^*	$AP(s^*, t_n^*, r^*)$
F_g	750	1176.98	0.00125	59957.9	2777.66	0.00568	63055.5
	625	1176.98	0.00125	59959.2	1650.8531	0.00508	85556.9
	375	1176.99	0.00125	59961.9	1190.047	0.00352	867980
	250	1176.99	0.00125	59963.2	1149.798	0.00250	976333
V_g	0.3	1176.99	0.00125	59961.4	1365.398	0.00389	140701
	0.25	1176.99	0.00125	59960.9	1312.872	0.00415	128022
	0.15	1176.88	0.00125	59960.1	1213.315	0.00462	108024
	0.1	1176.88	0.00125	59959.7	1165.744	0.00484	99904.3
h_1	0.15	1183.14	0.00120	57452.6	1283.924	0.00422	122956
	0.125	1180.16	0.00122	58219.1	1273.427	0.00430	125153
	0.075	1173.61	0.00127	61675.2	1250.413	0.00451	134355
	0.05	1170	0.00130	62361.5	1237.747	0.00459	141350
h_2	0.3	1188.63	0.00115	54849.9	1303.206	0.00406	108386
	0.25	1183.14	0.00120	57452.6	1283.924	0.00421	112956
	0.15	1170	0.00130	62361.5	1237.747	0.00458	111350
	0.1	1162	0.00130	64640.3	1209.621	0.00481	125099
h_3	0.45	1193.56	0.00110	51162.5	1320.526	0.00393	98779.8
	0.375	1185.96	0.00117	56662.4	1293.833	0.00415	113607
	0.225	1166.14	0.00133	61017.2	1224.186	0.00469	125699
	0.15	1152.7	0.00144	67778.2	1176.928	0.00507	138480
p_1	1500	1176.99	0.00125	59960.5	1262.280	0.00439	117288
	1250	1176.99	0.00125	59960.5	1262.280	0.00439	117288
	750	1176.98	0.00125	59960.5	1262.280	0.00439	117288
	500	1176.98	0.00125	59960.5	1262.279	0.00439	117288
p_2	1350	1176.99	0.00125	59960.6	1262.280	0.00439	117288
	1125	1176.99	0.00125	59960.6	1262.280	0.00439	117288
	675	1176.98	0.00125	59960.5	1262.279	0.00439	117288
	450	1176.98	0.00125	59960.4	1262.279	0.00439	117288
p_3	1200	1176.99	0.00125	60023.4	1365.554	0.00260	141044
	1000	1176.99	0.00100	59998.2	1312.956	0.00331	128213
	600	1176.98	0.00166	59898.1	1213.222	0.00616	107752
	400	1176.98	0.00250	59773.5	1165.549	0.00968	99151.1
e_p	25.5	1164.23	0.00125	59871.4	1217.503	0.00439	115465
	21.25	1170.61	0.00125	59916.4	1239.891	0.00439	116390
	12.75	1183.36	0.00125	60004.0	1284.668	0.00439	118159
	8.5	1189.74	0.00125	60046.7	1307.057	0.00439	119004
E_g	0.0075	1124.23	0.00125	59471.4	1213.503	0.00439	115065
	0.00625	1130.61	0.00125	59516.4	1235.891	0.00439	115990
	0.00375	1143.36	0.00125	59604.0	1280.668	0.00439	117759
	0.0025	1149.74	0.00125	59646.7	1303.057	0.00439	118604
NO_x	1.68	1134.98	0.00125	59656.0	1114.781	0.00439	110874
	1.4	1155.98	0.00125	59812.2	1188.531	0.00439	114227
	0.84	1197.99	0.00125	60100.9	1336.031	0.00439	120057
	0.56	1218.99	0.00125	60233.5	1409.781	0.00439	122537
SO_x	2.85	1153.23	0.00125	59792.2	1178.872	0.00439	113805
	2.375	1165.11	0.00125	59877.6	1220.576	0.00439	115593
	1.425	1188.86	0.00125	60040.9	1303.984	0.00439	118889
	0.95	1200.74	0.00125	60118.8	1345.687	0.00439	120398

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