

A Survey on Multi-Product Sustainable Economic Production Quantity Model Considering Wastewater Emission Costs

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Abstract. Implementing sustainability in production processes is the goal of many companies. A traditional economic production quantity (EPQ) model is used to determine the optimal number of products to produce in one period. Few researchers have considered carbon emission costs. In this study, we made a survey on multi-product sustainable economic production quantity model considering wastewater emission costs. The objective of this study is investigate the possible research to determine the economic production quantity to minimize the total costs per production cycle and waste emissions. The survey consider researches under three scenarios: (1) sustainable EPQ model that considers all CO₂ emissions from inventory holding and production; (2) sustainable EPQ with shortage backorder; and (3) multi-product sustainable EPQ model with shortage.

1. Introduction

Wastewater emission and demand for fresh water continues to increase with industrialization. Wastewater emission is a known global problem, where 80% of water effluents from various industries is discharged into rivers, lakes, and oceans that are left untreated [1], eventually leading to eutrophication, human health risks and water scarcity. Efforts to address these problems are already done by various researchers, utilizing different process integration methods to reduce water emission in industrial plants. These include linear models [2], nonlinear models [3], pinch analysis [4], genetic algorithms [5], management strategies [6], benchmarking [7], and wastewater reuse, recovery, and treatment methods [8].

Harmful gaseous releases are also produced from manufacturing industries, including carbon dioxide (CO₂), sulphur oxides (SO_x), nitrogen oxides (NO_x), and methane (CH₄) emissions. These gases are emitted through fossil fuel combustion, production, transportation, and other procedures. A 2016 study [9] revealed that annual CO₂ emission can go up to 11 million tons and is continually increasing while SO_x and NO_x emissions have increased during the years 1990 and 2016 respectively due to continuous fuel combustion [10]. In contrast, CH₄ emission associated from landfills, coal mining, and distribution of natural gas and petroleum products have decreased. CH₄, however, still impacts the environment on a global scale as a greenhouse gas (GHG) due to its high global warming potential compared to other GHGs. Similarly, numerous researches have been conducted to address



GHG emission problems, focusing on inventory management [11], fuel saving strategies [12], and optimizing transshipment routes [13].

The problems regarding emission of pollutants are still not solved although information and procedures on how to integrate processes considering environmental factors are readily available. This may be attributed to the substantial costs and expenses for the implementation of sustainable processes, a main barrier to achieve a cleaner production system [14]. Other researchers linked the problem to the Green Attitude-Behaviour Gap of consumers, a term defined by [15] as the comparison between favourable attitude of customers and their actual purchasing activities for green products. It noted that consumers are more concerned with product price than green product attributes. This means that implementing sustainability is a challenge to industries.

Numerous researchers have already done the extension of the EPQ model. Some studies considered different types of demand [16], incorporated shortage situations [17], and included deteriorating rates [18]. Researches on sustainable inventory models integrating environmental costs through direct accounting approach are also available since there is a fervent need for environmental sustainability management. These include the work of Taleizadeh et. al. [17], where an EPQ model is integrated to have carbon emission costs through direct accounting approach considering different shortage situations, and Zadfajar and Gholamian [2] who developed an inventory model that considers the emission of SO_x, NO_x, BOD, and COD from the manufacturing process of pulp and paper mills and its water effluents. The model was developed using exact non-linear constrained solution method. Another research [19] created a sustainable EPQ model considering carbon emission from production, warehousing, and waste disposal activities then extended it to a full backordering situation.

This paper aimed to provide a more realistic EPQ model that can be used to determine the right quantity to produce while minimizing the total costs per production cycle, taking into account of sustainable issues. Studying the EPQ model is more logical since water effluents and GHG emissions are more apparent during production processes. The sustainable EPQ model extends the study by [17] to consider a full backordering and multi-product situations. The model applies optimization methods to consider CO₂ emission cost, wastewater costs and BOD/COD emission. Finally, the CH₄ emission was incorporated from the waste disposal procedure.

As the world's need for environmental sustainability management grows, tax laws and emission costs are continuously imposed on various industries. However, companies still tend to exclude sustainability management on their system because of the costs and expenses that comes with its implementation and maintenance. The costs may be compromised by increasing the product price, but the consumers would be less willing to purchase the product. For these reasons, the manufacturers must reduce cost by optimizing an EPQ model. Production processes are the main sources of harmful emissions for a manufacturing system. In order to become more globally competitive, manufacturers would want to consider sustainability in their production system without affecting or minimizing their total cost.

2. Finding the Gap: Literature Review

2.1. Sustainable Inventory Models

The EOQ model, developed by [20] in 1913 help companies determine the optimal quantity to order. Two years after, the same author extended his work by presenting a model for finding the EPQ that involves only holding and set-up costs. Since then the importance of environmental issues, sustainable development, and concept of sustainability receives more attention than before [21]. As newer sustainable machines and treatment processes are invented for different types of industries, both producers and buyers are still not accustomed to applying sustainability in the production system because of the implementation costs and expenses [14]. By then, numerous researchers studied and developed sustainable inventory models to respond to environmental needs of the corporate world. In a recent study by [17], four (4) sustainable EPQ models were analysed and applied to different shortage situations. Using direct accounting approach, the researchers developed the sustainable EPQ (SEPQ) with carbon emission costs from holding, obsolescence, and production under different backordering situations. The study revealed that although these did not generate the least cost; an

SEPB with partial model is the ideal and realistic model to use. Similarly, [19] developed an SEPB model through optimization methods considering carbon emission costs from production, warehousing, and waste disposal activities for a full backordering situation. A broader perspective has been adopted by [22], who implemented a study to a single-vendor single-buyer situation accounting for carbon emission from transporting, warehousing, and inventory holding of deteriorating items. This provided insights on determining the optimal production quantity while minimizing total inventory and carbon emission costs. The work of [2] on the other hand, presented a revised EOQ model by adding income from waste sales as well as sulphur, nitrogen, BOD, and COD emission costs. The investigators compared all the developed models to the real data from a pulp and paper mill in Iran and found that through environmental ergonomics, both inventory costs and emissions can be minimized. Together these studies provided important insights to both the manufacturers and buyers in implementing system sustainability. This study will attempt to fill the gaps and add new considerations in the models developed from past researches.

2.2. Pulp and Paper Mill Industry

Numerous literatures on sustainability to various types of industries including the pulp and paper mill industry is evident over the years. This industry has been receiving widespread attention due to its high-energy consumption [23]. The pulp and paper mill industry generate different pollutants that depend on the type of pulping process [8]. Paper production includes three (3) major activities: pulp making, paper formation, and finishing. During the pulp making and paper formation process, coatings and fillers are added to the pulp that converts it into paper. This process requires an intensive resource and energy that results to huge emission of GHGs, water effluents, and other pollutants [24]. Various researches on sustainability methods include generating environment-friendly management strategies [6], treatment processes [8], and integration of inventory models [2].

2.3. Emissions during the Pulp and Paper Production

The emissions of pulp and paper processes are presented in Table 1. Wood handling, pulping, and chemical recovery units emit specific amounts of SO_x in each process. It can also be observed that NO_x emissions are present only in pulping and chemical recovery. Wastewater emission can be found in all units except in packaging while wastewater treatment unit produces refined water (BOD and COD) and dry sludge. The dry sludge is then disposed to landfills that produce methane. Evidently, air and water pollutions are present in the pulp and paper mill industry.

Table 1. Source of Emissions from a Pulp and Paper Mill Process

Considered Processes	NO _x	SO _x	BOD	COD	CO ₂	CH ₄
Wood Handling	•	•	•	•		
Pulping		•	•	•		
Chemical Recovery	•	•				
Pulp Washing			•	•		
Pulp Bleaching			•	•		
Paper Making			•	•		
Finished Paper Storage						
Wastewater Treatment			•	•		
Disposal of Solid Waste (Dry Sludge)						•
Whole Production Process (Electricity)					•	

3. Conclusion

This study focuses on literature review for sustainable Economic Production Quantity (EPQ) models. At proposal to extend the sustainable EPQ model is then suggested to consider shortage and multi-product production system with warehouse capacity constraint. The main goal is to provide insights

for researcher to minimize GH emission and the total cost per production cycle. If a manufacturer applies the proposed models to their current system, the company will become more sustainable and cost effective. The proposed sustainable EPQ models may provide significant insights to various manufacturing industries. Future research can focus on other objectives such as decreasing emission of hazardous wastes during production and broadening the models to consider simultaneously the perspectives of the manufacturer and the buyer.

4. References

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