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The Effect of Renewable Energy and Corporate Social Responsibility on Dual-Channel Supply Chain Management

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Abstract: Global energy demand has unquestionably increased significantly in recent years. Nowadays, industries are very aware of global warming, and to save the environment, they produce green products with energy consumption. Day by day, energy use is increasing due to population, end-use markets of construction, transportation, industry, etc. But the energy limit is finite, whereas the daily use is rising, so the price is increasing. In this study, two situations have been shown in two models with renewable energy consumption. Model 1 analyzes the manufacturer and retailer's optimal green quality and sales price in two-echelon supply chain systems with centralized and decentralized cases. In this case, the retailer sells their products through three different channels: online, offline, and buy-online-pickup-in store, with three different selling prices. In Model 2, Manufacturer 1 and Manufacturer 2 produce green and regular products with renewable energy consumption. In this case, both manufacturers sell their products through three different channels: online, offline, and buy-online-pickup-in store, with three different selling prices. There is competition between substitutable products with respect to green quality and the selling price of the products. A hybrid channel policy is studied here to maximize the total profit with considering corporate social responsibility under renewable energy consumption. The study has been analyzed mathematically. The classical optimization approach and game theory are applied here to find the optimal values of procurement cost, selling price, and green quality development cost. A numerical study shows that the centralized system gives a better result to the manufacturer than the decentralized system. When the demand is a power function of the selling price, the manufacturer producing eco-friendly products gains 0.99% more profit than the conventional product. This result shows that manufacturers creating eco-friendly products motivate other manufacturers to make eco-friendly products.

Keywords: renewable energy; sustainable supply chain model; hybrid channel; price competition; corporate social responsibility

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1. Introduction

The use of renewable energy technology and sources must be expanded not just for electricity production but also for the end-use markets of construction, transportation, and industry. By 2040, it is predicted that energy generation will have increased by 52% due to the projected two billion rise in world population over the following two decades and rising living standards (https://www.capp.ca/energy/world-energy-needs/). There are limited non-renewable energy sources, but demand is increasing daily, so the pricing also becomes higher. Also, using renewable energy makes the environment more polluted, whereas using non-renewable energy emits so much carbon-di-oxide (https://www.ucsusa.org/resources/environmental-impacts-renewable-energy-technologies). From fossil fuels, around 80% of the world's energy and 66% of electrical are derived from which 60% greenhouse gas is derived, which is responsible for global warming. About 20% of the electricity in the United States is produced by renewable energy. To reduce greenhouse gases, renewable energy sources are more reliable and suitable than fossil fuels (Kiehbadroudinezhad et al. [1]). One of the essential infrastructure components is power, which is necessary for any nation's welfare and economic progress. Due to the quick depletion of fossil fuels, engineers have been pushed to consider renewable energy consumption. Many researchers have worked on renewable energy. Singh et al. [2] examined wind power as renewable energy. It has grown in popularity to use a hybrid renewable energy system (HRES), which combines many renewable energy sources (Ming et al. [3]). About renewable energy sources in Ecuador, Arroyo, and Miguel [4] offered a comparative study of energy governance. Li et al. [5] investigated the relationship between renewable energy sources and the SAARC nations' economic development. It was found that renewable hydropower energy is more powerful for economic growth. Czarnecka et al. [6] showed energy sector firms' use of social media to communicate with consumers, which has grown in recent years. And it investigated if consumer social media participation influences how people view the green energy business model and how the attitudes and actions of social media users impact this perception.

A challenging job for supply chain management in a particular economy has a complex problem when integrating environmental and social issues considerations (Maciaszczyk et al. [7]). To address this problem, firms have taken numerous creative and environmentally friendly business tactics under renewable energy consumption (Moller and Krauter [8]). Every country is trying to keep their environment pollution-less and tries to develop towards sustainability (Kwasek et al. [9]). Programs to raise awareness of environmental issues, create green products and technologies, and reduce carbon emissions are all part of sustainable development (Lee et al. [10]). Among other things, supply chain management has considerable challenges with regard to operations and investments in green product development (GDP). As every customer is aware of greening, the manufacturer also focuses on greening and trying to be more environmentally friendly. To give attention to greening manufacturer pays some money to make the product greening and to make the environment pollution-free, the manufacturers use renewable energy instead of conventional energy and also try to consume renewable energy. Nowadays, the Government, even industries, and customers are concerned about protecting the environment as it shows that the manufacturing industries are responsible for pollution (https://storymaps.arcgis.com/stories/7221608f86ae406f802d294a51f690f3).

To go towards sustainability under renewable energy consumption, GDP is gaining the interest of everyone, and the use of green products plays a vital role in developing the system towards sustainability (Vasylieva et al. [11]). Nowadays, industries need to act socially responsible and assure the public that their methods for maximizing profits would cause the least environmental damage (Cash et al. [12]). Many industries adopt corporate social responsibility (CSR) to solve social issues and compete with the monopoly market. In this practice, industries invest money in society to develop education, health, etc. For decades, one field that has been overgrown in supply chain management is the incorporation of CSR. CSR, sustainability, i.e., corporate sustainability (CS) strategies must consider the organization's ability to maintain its financial and physical viability as well as its people and social resources. In the sustainable development goal (SDG) agenda, there are 17 goals (https://sdgs.un.org/goals). The leading countries are Finland, Sweden, and Germany for the 2030 agenda of SDG (https://www.activesustainability.com/sustainable-development/are-countries-achieving-the-sustainable-development-goals?$_$adin=02021864894). For the SDG, different countries contribute in different ways. By section 135 of the Companies Act 2013, companies in India must implement a CSR program that contributes at least 2% of the average net profit over the previous three years to the community (https://bthechange.com/csr-in-india-is-now-a-law-2502aa6d0daa).

Every industry adopts some strategies to enhance CSR. In this study, industries adopt a hybrid retailing strategy. Nowadays, a hybrid channel is a trending culture in the business world. Everyone has a packed daily agenda and does not have time to waste. That is why everyone likes to purchase products online, and industries capture this strategy in their business to get more profit (Maciaszczyk et al. [13]). For online, the trust issue is a big challenge. Therefore, a new policy named 'buy online and pick up in store' (BOPS) has been introduced, allowing customers to choose the products online and collect their products at the nearest retail store. Thus, hybrid channels combined with online, offline, and BOPS is the most effective practice in the industry. The hybrid retailing strategy is beneficial for the industry, but the industry needs to think about social responsibility also. Companies are putting more and more effort into their CSR initiatives all across the world. An essential activity among CSR initiatives is a donation. Donations enable businesses to improve their position and goodwill and can get attention from the general public. Also, there are many benefits of CSR namely, a healthy relationship buildup between supply chain members, increased media reputation and reputation, increased customer satisfaction and demand, energy and operating cost savings, etc. For online retailing channels, there is no need to go to the retail shop, and in that case carbon emissions due to transportation decrease, which helps to build up a pollution-less environment. For the BOPS channel, the lead time will be reduced. If a customer has an emergency to buy a particular product, then the customer just checks online, orders the product, and goes to the shop to pick up the product. In that case, customer satisfaction is fulfilled and lead time is reduced. Therefore, the hybrid channel helps the customers to satisfy their demands as their wish. That means hybrid channels can fulfill the customer's satisfaction which is a benefit of CSR. Also, the hybrid channel implementation helps the industry to gain more profit which helps the industry to give some percentage of the profit to society as a donation through CSR. And all the benefits of CSR are closely fulfilled when the companies choose hybrid channels for product selling. The paper is structured as follows: Section 2 describes the current literature-related study, and the research gap is explained. Problem explanation, symbols, and presumptions have been listed in Section 3. In Section 4, the Model formulation has been described. Numerical examples are made to validate the model in Section 5. There are some managerial insights in Section 6, and last, in Section 7, conclusions have been performed.

1.1. Research Gap of the Study

1. In previous literature (Sana [14], Sarkar et al. [15]), the products have been sold to customers through offline retail channels. There is no consideration of online channels and BOPS channels under renewable energy consideration.
2. There are so many studies on CP (Choi et al. [16], Hota et al. [17]). There is no study on EFP through three retail channels under renewable energy consumption.
3. Two manufacturers share some percentage of total profit to society through CSR. The market price competition between CP and EFP products with the greenness level of the product under renewable energy consumption is studied here.

1.2. Objective of the Study

Nowadays every industry tries to use renewable energy in their system and reduce renewable energy consumption. Everyone wants a pollution-less environment and that is why people choose green products. Therefore, the main objectives are when M1 produces EFP, gets more profit than M2, and the market competition between EFP and CP are studied here. Also, every industry opens online, offline, and BOPS channels to give customers better service. Through three different channels, the industry gets more profit, which helps to serve society development as CSR. The study wants to find out the following points.

1. The EFP's price and quality under renewable energy consumption when Manufacturer 1 (M1) has the information about the conventional item's price, and the CP's price

under renewable energy consumption when Manufacturer 2 (M2) has information about the EFP's price and quality.
2. The CP's price and the EFP's price and quality under renewable energy consumption in the centralized system when the pricing method and GQ are unknowable to M1 and M2.
3. The effect of CSR initiatives on green quality (GQ) and pricing under renewable energy consumption, and the differences between the centralized and decentralized sustainable supply chain model (SSCM) under renewable energy consumption.

1.3. Purpose of the Study

The main aim of this study is energy consumption using renewable energy to optimize the selling price of three different channels, green quality, business strategy of green marketing, and to make the environment pollution-less. Therefore, the industry gets more profit and the industry can serve some percentage of the total profit to society through CSR which makes society reliable.

1.4. Contribution of the Study

Recently, every sector of the company is going toward a hybrid business strategy under renewable energy consumption. Everyone tries to save valuable time without going to the shopping mall. The use of the internet and the growth of technology are increasing day by day. The companies are trying to open online and BOPS retail strategy with an offline retail store and therefore, the hybrid channel has been chosen. Nowadays, everyone is aware of the environment. Customers like EFP products that are less harmful to the environment rather than CP. Also, the manufacturer shares some percentage of the profit with society. This study analyzes the contribution of CSR and GQ of EFP in SSCM under renewable energy consumption.

1.5. Research Methodology

A classical optimization technique and Stackelberg game approach have been applied here to get the feasibility of the solution. In a game theory, there are three cases. It is not always possible for the supply chain members to have equal power to make decisions. One has to follow another. Sometimes the manufacturer is the leader, and the retailer is the follower. Sometimes the retailer is the leader, the manufacturer is the follower, and sometimes they make decisions jointly. In a classical optimization technique, the first-order partial derivatives of the profit function with respect to decision variables equate to zero and find the optimum values. To prove the sufficient condition Hessian matrix has been performed.

2. Literature Review

Manufacturing industries are responsible for environmental pollution, which negatively affects the human body (Kalaiarasan et al. [18]). People must take responsibility for protecting the environment by utilizing more eco-friendly items to resolve this problem. The existing literature on renewable energy, SSCM, EFP, hybrid channels, and CSR are discussed below. Table 1 shows the study contributions along with research gaps.

Table 1. Study contributions along with research gaps.

Author(s)	Model Type	Renewable Energy	Selling Mode	Green Product	Regular Product	Price Competition	CSR
Czarnecka et al. (2022) [6]	GEBM	Yes	No	Yes	No	No	No
Dey et al. (2023) [19]	SCM	No	Yes	No	Yes	No	No
Ming et al. (2017) [3]	HRES	Yes	No	No	No	No	No
Mondal and Giri (2020) [20]	SCM	No	No	Yes	No	No	Yes
Kar et al. (2023) [21]	PM	No	Yes	No	Yes	No	No
Sana (2021) [14]	SCM	No	No	Yes	Yes	Yes	Yes
This study	SSCM	Yes	OOBOPS	Yes	Yes	Yes	Yes

OAO: Online and offline; OOBOPS: Online-offline-BOPS; SCM: Supply chain model; PM: Production model; SSCM: Sustainable supply chain model; GEBM: Green energy business models; HRES: Hybrid renewable energy system.

2.1. Corporate Social Responsibility

CSR is widely practiced in emerging markets and is advancing globalization through business activities undertaken by multinational corporations (Berniak-Wozny et al. [22]). Through CSR customer satisfaction and demand for the product in the market are increased. Also, one of the main benefits of CSR is operating costs and energy can be decreased. If a company sells its products through hybrid channels, it is easy to know the customers about the benefit of CSR. Also, the hybrid channel helps the company to gain more profit by increasing its demand. Vosooglidizaji et al. [23] presented an SSCM in which all participants share profit through CSR under information asymmetry. Ali and Kaur [24] showed the impact of CSR on society's application in developing nations. Quarshie et al. [25] highlighted sustainability in SCM under CSR. Modak et al. [26] presented an article that enlisted all journals and publications in which there was a model related to the synthesis of CSR in SCM. Singh et al. [27] established a sustainable biodiesel supply chain model through a triple bottom line approach. Focusing on GQ, CSR, and hybrid channels in SSCM, this study has been established where the existing literature does not contain all these practices. This is the research gap of this study.

2.2. Sustainable Supply Chain Management

Sustainability is a significant factor in the modern world because of economics that is continually growing and rising demand (Sarkar et al. [28], Stange et al. [29]). The application of sustainability in the supply chain model (SCM) has been promoted by numerous researchers (Said et al. [30]). Sana [14] showed the sustainability in the two-echelon SCM by producing EFP and sharing profits for society development. Mridha et al. [31] established a sustainable smart biofuel production system that minimizes carbon emissions & energy. Hota et al. [17] presented a two-echelon supply chain model with a reliable retailer and an unreliable retailer, and selling price-dependent demand. Nilsson and Goransson [32] explained the essential elements of sustainable supply chain innovation and guided how to handle these elements throughout the creative process. Bortolin et al. [33] presented a sustainable supply chain network design in which it is advised how to minimize the stock, cost, and environmental issues. Mogale et al. [34] presented a multi-objective optimization model considering multi-echelon, multi-mode, multi-period, and multi-product. Mridha et al. [35] established an SSCM model with biofuel production quality improvement under carbon emissions reduction. For sustainable supply chain management to be successfully implemented in the electronic industry, it is essential to develop specific policies at both the organizational and governmental levels (Menon and Ravi [36]). Many researchers have established SSCM, but no one has considered the SSCM model with CSR under a hybrid channel.

2.3. Selling Mode

Nowadays, every industry imposes different channels to sell the products as a new business policy in SSCM (Kar et al. [21]). Online channel and BOPS channel policy is a new concept in business, and many customers like to shop for products through these channels along with the retail store. Much research has been done on this topic. Choi et al. [16]

presented an imperfect production system with controlling lead time and selling the products through online channels and offline channels. Dey et al. [19] showed online-to-offline retailing strategies on a supply chain model with a free home delivery system under a certain amount of products a customer has to be purchased. Sarkar et al. [37] presented a 'smart production system' where defective products are identified through autonomation technology. The good products and remanufacturing products both were sold through online channels and offline channels.

2.4. Eco-Friendly Product, Conventional Product, and Price Competition

The function of EFP in a sustainable supply chain as a tactic to boost competition and take on more market share has been the subject of an expanding body of research in recent years. In this direction, many researchers are working on EFP. Wang et al. [38] established a green SCM with CSR activity and analyzed that green SCM and CSR activity both positively impact their model. Mondal and Giri [20] established an SCM where demand depends on GQ. Shi et al. [39] explained the relationship between marketing and EFP development in an SSCM. Many researchers have presented models on EFP no one considered a hybrid channel which is a huge research gap in the study. To solve the study numerically, the Stackelberg game theory and classical optimization approach have been used here. Holmstrom et al. [40] researched design science in different approaches.

3. Materials

Problem definition, notations, and assumptions used to develop the model are described in different subsections.

3.1. Problem Definition

In the model, a sustainable supply chain model considering one manufacturer and one retailer has been considered with green product development. Later, two manufacturers produce EFP and CP, respectively, and they sell their products through online, offline, and BOPS channels. The demand function is a function of the selling price and GQ. The demand function is assumed as a linear and power function of the selling price in different models. At last, the competition between two products, i.e., EFP and CP, have been made through CSR as both firms are socially responsible. Renewable energy has been considered due to the production of products and the greenness of products.

3.2. Assumptions

The following assumptions are taken to formulate the model.

1. A SSCM is developed with a single manufacturer and retailer for EFP under renewable energy.
2. No holding cost is considered here as it is assumed that the retailer follows a just-in-time policy and the manufacturer produces the products as per order.
3. Supply chain members invest in developing EFP, and demand depends on GQ and selling price.
4. M1 and M2 produce EFP (P1) and CP (P2) under renewable energy consumption, which are substitutable types; therefore, there is competition on price to market capture.
5. M1 and M2 produce products as per order, and that's why there is no holding cost, and both firms share some percentage of profit to the society through CSR.
6. Retailer sells products to customers through three different modes: online, offline, and BOPS.

3.3. Notation

The following notations have been used to develop the model which is given in Table 2.

Table 2. Notation.

Index	
$i = 1, 2, 3$	Online, offline, BOPS channel
Decision variables	
p_i	retailer's selling price in i-th channel
g	level of the greenness of the product
p_{ig}	retailer's ith channel selling price for EFP
p_{in}	retailer's ith channel selling price for the CP
Parameters	
c	product's procurement cost
G	cost per unit greenness
s	selling price of manufacturer
$c^{'}$	Energy related cost due to procurement
$G^{'}$	Energy related cost due to greenness
a_i	Market capacity of the i-th channel
b_i, b_ig, b_in	scaling parameter
$\alpha(0 \leq \alpha \leq 1)$	manufacturer's fraction of investment for EFP development
d	market's demand
θ_m	profit of manufacturer
θ_r	profit of retailer
d_g	market demand for EFP
d_n	market demand for CP
θ_g, θ_n	profit after CSR activity for EFP and CP, respectively
θ	total profit of the centralized system
c_g, c_n	procurement cost of EFP and CP, respectively
$c_g^{'}, c_n^{'}$	Energy related cost due to procurement of EFP and CP, respectively
$\alpha, \beta(0 \leq \alpha, \beta \leq 1)$	fraction of investment earned from EFP and CP for development
n_i, m_i, l_i, k_i	scaling parameters

4. Mathematical Model Formulation and Methods

4.1. Model 1

An SCM has been made under renewable energy consisting of one manufacturer and one retailer. This case is under the green product development model in a monopolized market. The demand is a function of the selling price of different channels and GQ. The greenness is the main feature competing with the CP. The development cost for producing EFP is Gg which is shared by both manufacturer and retailer. In Case I, the demand is linearly dependent on the selling price; in Case II, the demand is the power function of the selling price. Renewable energy has been used for procurement costs and the development of green quality. Figure 1 shows the graphical representation of Model 1 and the research process.

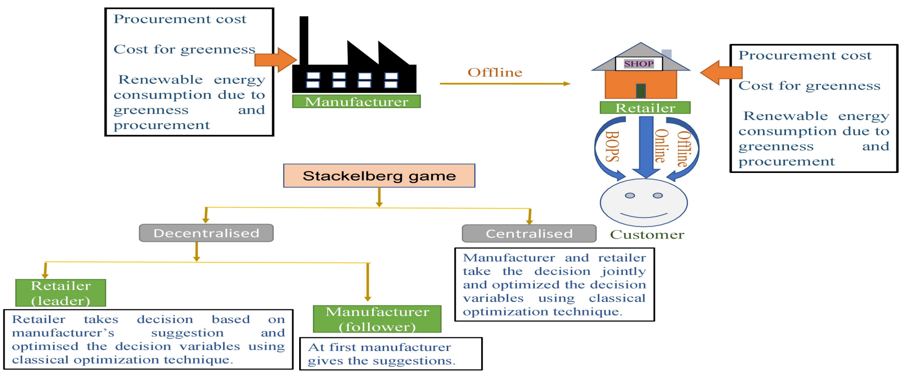

Figure 1. Graphical representation of Model 1 and research process.

4.1.1. Case 1

Total demand is the summation of the online demand, offline demand, and BOPS demand, and it is expressed as follows:

$$d(g, p_1, p_2, p_3) = \frac{g}{1+g}(a_1 + a_2 + a_3) - b_1 p_1 - b_2 p_2 - b_3 p_3.$$

The manufacturer has two types of costs due to renewable energy. One is for production and the other is for the development of EFP. Therefore, the manufacturer's profit with considering renewable energy is

$$\begin{aligned}
\theta_m(g, p_1, p_2, p_3) &= \text{Selling price} - \text{procurement cost} - \text{energy-related cost due to procurement} \\
&- \text{cost for greenness} - \text{energy-related cost due to greenness} \\
&= \left(s - (c + c')\right)\left(\frac{g}{1+g}a_1 - b_1 p_1\right) + \left(s - (c + c')\right)\left(\frac{g}{1+g}a_2 - b_2 p_2\right) \\
&+ \left(s - (c + c')\right)\left(\frac{g}{1+g}a_3 - b_3 p_3\right) - \alpha(G + G')g.
\end{aligned}$$

Retailer contributes to renewable energy cost due to the development of EFP. The retailer's profit with considering renewable energy is

$$\begin{aligned}
\theta_r(g, p_1, p_2, p_3) &= \text{Revenue} - \text{cost for greenness} - \text{energy-related cost due to greenness} \\
&= (p_1 - s)\left(\frac{g}{1+g}a_1 - b_1 p_1\right) + (p_2 - s)\left(\frac{g}{1+g}a_2 - b_2 p_2\right) \\
&+ (p_3 - s)\left(\frac{g}{1+g}a_3 - b_3 p_3\right) - (1 - \alpha)(G + G')g.
\end{aligned}$$

Therefore, the total profit of the centralized system is

$$\begin{aligned}
\theta(g, p_1, p_2, p_3) &= \left(p_1 - (c + c')\right)\left(\frac{g}{1+g}a_1 - b_1 p_1\right) + \left(p_2 - (c + c')\right)\left(\frac{g}{1+g}a_2 - b_2 p_2\right) \\
&+ \left(p_3 - (c + c')\right)\left(\frac{g}{1+g}a_3 - b_3 p_3\right) - (G + G')g.
\end{aligned}$$

This model has been divided into two systems: decentralized and centralized. These two types of systems have been analyzed below.

Decentralized System

In this case, it is assumed that the retailer is the leader and the manufacturer is the follower. Based on manufacturer's suggested optimal selling price, differentiation of the retailer's profit with respect to p_i, g are as follows:

$$\begin{aligned}
\frac{\partial \theta_r}{\partial p_i} &= \frac{g}{1+g}a_i - 2b_i p_i + b_i s, \forall i \\
\frac{\partial \theta_r}{\partial g} &= \left(\frac{1}{1+g}\right)^2 (a_1(p_1 - s) + a_2(p_2 - s) + a_3(p_3 - s)) - (1 - \alpha)(G + G') \\
\frac{\partial^2 \theta_r}{\partial {p_i}^2} &= -2b_i < 0, \forall i, (\text{as } b_1, b_2, b_3 > 0) \\
\frac{\partial^2 \theta_r}{\partial g \partial p_i} &= \frac{\partial^2 \theta_r}{\partial p_i \partial g} = \left(\frac{1}{1+g}\right)^2 a_i, \forall i \\
\frac{\partial^2 \theta_r}{\partial g^2} &= -\frac{2((a_1(p_1 - s) + a_2(p_2 - s) + a_3(p_3 - s))}{(1+g)^3} < 0, \text{ as } p_1 > s,\ p_2 > s, \text{ and } p_3 > s
\end{aligned}$$

To get the optimum value of θ_r, $\frac{\partial\theta_r}{\partial p_i} = 0$ gives $p_i = \frac{1}{2b_i}(\frac{g}{1+g}a_i - b_i s)$ and $\frac{\partial\theta_r}{\partial g} = 0$ gives $(1+g)^3 + 3A(1+g) + B = 0$, where $A = \frac{\frac{a_1^2 - a_1 b_1 s}{b_1} + \frac{a_2^2 - a_2 b_2 s}{b_2} + \frac{a_3^2 - a_3 b_3 s}{b_3}}{6(1-\alpha)(G+G')}$ and $B = \frac{a_1^2 b_2 b_3 + a_2^2 b_1 b_3 + a_3^2 b_2 b_1}{2(G+G')b_1 b_2 b_3 (1-\alpha)}$.

Proposition 1. *The profit function θ_r obtains maximum value at $({p_1}^*, {p_2}^*, {p_3}^*, g^*)$ when the following propositions are satisfied:* $p_i^* = \frac{1}{2b_i}\left(\frac{g^*}{1+g^*}a_i + b_i s\right), (1+g^*)^3 + 3A(1+g^*) + B = 0 \; \forall i$, $\forall g^* \in [\frac{b_1 s}{a_1 - b_1 s}, \infty) \cap [\frac{b_2 s}{a_2 - b_2 s}, \infty) \cap [\frac{b_3 s}{a_3 - b_3 s}, \infty) \cap \left(-1 + \frac{\frac{a_1^2}{b_1} + \frac{a_2^2}{b_2} + \frac{a_3^2}{b_3}}{2\left(\frac{a_1^2}{b_1} + \frac{a_2^2}{b_2} + \frac{a_3^2}{b_3} - s(a_1 + a_2 + a_3)\right)}, \infty\right)$.

Proof. Hessian matrix is performed here to prove the concavity globally. $|H_{11}| = -2b_1 < 0$, $|H_{22}| = 4b_1 b_2 > 0, |H_{33}| = -8b_1 b_2 b_3 < 0, \theta_r$ attains maximum value at $({p_1}^*, {p_2}^*, {p_3}^*, g^*)$ if $|H_{44}| > 0$. Now, $|H_{44}| > 0$ implies that $g > -1 + \frac{\frac{a_1^2}{b_1} + \frac{a_2^2}{b_2} + \frac{a_3^2}{b_3}}{2\left(\frac{a_1^2}{b_1} + \frac{a_2^2}{b_2} + \frac{a_3^2}{b_3} - s(a_1 + a_2 + a_3)\right)}$. $p_1 > s$, $p_2 > s$, $p_3 > s$ implies $g > \frac{b_1 s}{a_1 - b_1 s}$, $g > \frac{b_2 s}{a_2 - b_2 s}$, $g > \frac{b_3 s}{a_3 - b_3 s}$ respectively. Hence the Proof. □

Here manufacturer is considered a follower. Hence the manufacturer's profit with considering renewable energy is $\theta_m = \left(s - (c + c')\right)\left(\frac{g^*}{1+g^*}a_1 - b_1 {p_1}^*\right) + \left(s - (c + c')\right)\left(\frac{g^*}{1+g^*}a_2 - b_2 {p_2}^*\right) + \left(s - (c + c')\right)\left(\frac{g^*}{1+g^*}a_3 - b_3 {p_3}^*\right) - \alpha(G + G')g^*$.

Centralized System

In this case, the manufacturer and retailer decide jointly and find the optimum values for the total profit. Differentiation of the retailer's profit with respect to p_i, g are as follows:

$$\begin{aligned}
\frac{\partial\theta}{\partial p_i} &= \frac{g}{1+g}a_i - 2b_i p_i + b_i(c + c'), \forall i \\
\frac{\partial\theta}{\partial g} &= \left(\frac{1}{1+g}\right)^2 \left(a_1\left(p_1 - (c + c')\right) + a_2\left(p_2 - (c + c')\right) + a_3\left(p_3 - (c + c')\right)\right) - (G + G') \\
\frac{\partial^2\theta}{\partial {p_i}^2} &= -2b_i < 0, \forall i, \forall i, (\text{as } b_1, b_2, b_3 > 0) \\
\frac{\partial^2\theta}{\partial g \partial p_i} &= \frac{\partial^2\theta}{\partial p_i \partial g} = \left(\frac{1}{1+g}\right)^2 a_i, \forall i \\
\frac{\partial^2\theta}{\partial g^2} &= -\frac{2((a_1\left(p_1 - (c + c')\right) + a_2\left(p_2 - (c + c')\right) + a_3\left(p_3 - (c + c')\right))}{(1+g)^3} < 0, \text{ as } p_1 > s,\ p_2 > s, \\
&\quad \text{and } p_3 > s
\end{aligned}$$

To get the optimum value of θ, $\frac{\partial\theta}{\partial p_i} = 0$ gives $p_i = \frac{1}{2b_i}(\frac{g}{1+g}a_i - b_i(c + c'))$ and $\frac{\partial\theta}{\partial g} = 0$ gives $(1+g)^3 + 3A(1+g) + B = 0$, where $A = \frac{\frac{a_1^2 - a_1 b_1 (c+c')}{b_1} + \frac{a_2^2 - a_2 b_2 (c+c')}{b_2} + \frac{a_3^2 - a_3 b_3 (c+c')}{b_3}}{6(G+G')}$ and $B = \frac{a_1^2 b_2 b_3 + a_2^2 b_1 b_3 + a_3^2 b_2 b_1}{2(G+G')b_1 b_2 b_3}$.

Proposition 2. *The profit function θ obtains maximum value at $({p_1}^*, {p_2}^*, {p_3}^*, g^*)$ when the following propositions are satisfied:*

$p_i^* = \frac{1}{2b_i}\Big(\frac{g^*}{1+g^*}a_i + b_i(c+c^{'})\Big), (1+g^*)^3 + 3A(1+g^*) + B = 0\ \forall i,\ \forall g^* \in [\frac{b_1(c+c^{'})}{a_1-b_1(c+c^{'})}, \infty) \cap [\frac{b_2(c+c^{'})}{a_2-b_2(c+c^{'})}, \infty) \cap [\frac{b_3(c+c^{'})}{a_3-b_3(c+c^{'})}, \infty) \cap \Bigg(-1 + \frac{\frac{a_1^2}{b_1}+\frac{a_2^2}{b_2}+\frac{a_3^2}{b_3}}{2\big(\frac{a_1^2}{b_1}+\frac{a_2^2}{b_2}+\frac{a_3^2}{b_3}-(c+c^{'})(a_1+a_2+a_3)\big)}, \infty\Bigg).$

Proof. Hessian matrix is performed here to prove the concavity globally. $|H_{11}| = -2b_1 < 0$, $|H_{22}| = 4b_1b_2 > 0, |H_{33}| = -8b_1b_2b_3 < 0, \theta$ attains maximum value at $(p_1{}^*, p_2{}^*, p_3{}^*, g^*)$ if $|H_{44}| > 0$. Now, $|H_{44}| > 0$ implies that $g > -1 + \frac{\frac{a_1^2}{b_1}+\frac{a_2^2}{b_2}+\frac{a_3^2}{b_3}}{2\big(\frac{a_1^2}{b_1}+\frac{a_2^2}{b_2}+\frac{a_3^2}{b_3}-(c+c^{'})(a_1+a_2+a_3)\big)}$. $p_1 > (c+c^{'})$, $p_2 > (c+c^{'}),\ p_3 > (c+c^{'})$ implies $g > \frac{b_1(c+c^{'})}{a_1-b_1(c+c^{'})},\ g > \frac{b_2(c+c^{'})}{a_2-b_2(c+c^{'})},\ g > \frac{b_3(c+c^{'})}{a_3-b_3(c+c^{'})}$, respectively. Hence the Proof. □

4.1.2. Case 2

Considering the market demand depends on a power function of three different channel's selling prices then, the demand function is as follows:

$$d = \frac{g}{1+g}\bigg(a_1p_1^{-n_1} + a_2p_2^{-n_2} + a_3p_3^{-n_3}\bigg).$$

The manufacturer has two types of costs due to renewable energy. One is for production and the other is for the development of EFP. Therefore, the manufacturer's profit with considering renewable energy is

$$\begin{aligned}
\theta_m &= \text{Selling price} - \text{procurement cost} - \text{energy-related cost due to procurement} \\
&- \text{cost for greenness} - \text{energy-related cost due to greenness} \\
&= \Big(s-(c+c^{'})\Big)\bigg(\frac{g}{1+g}a_1p_1^{-n_1}\bigg) + \Big(s-(c+c^{'})\Big)\bigg(\frac{g}{1+g}a_2p_2^{-n_2}\bigg) \\
&+ \Big(s-(c+c^{'})\Big)\bigg(\frac{g}{1+g}a_3p_3^{-n_3}\bigg) - \alpha(G+G^{'})g.
\end{aligned}$$

Retailer contributes to renewable energy cost due to the development of EFP. The retailer's profit with considering renewable energy is

$$\begin{aligned}
\theta_r &= \text{Revenue} - \text{cost for greenness} - \text{energy-related cost due to greenness} \\
&= (p_1-s)\bigg(\frac{g}{1+g}a_1p_1^{-n_1}\bigg) + (p_2-s)\bigg(\frac{g}{1+g}a_2p_2^{-n_2}\bigg) \\
&+ (p_3-s)\bigg(\frac{g}{1+g}a_3p_3^{-n_3}\bigg) - (1-\alpha)(G+G^{'})g.
\end{aligned}$$

The total profit of the centralized system is

$$\begin{aligned}
\theta &= \Big(p_1-(c+c^{'})\Big)\bigg(\frac{g}{1+g}a_1p_1^{-n_1}\bigg) + \Big(p_2-(c+c^{'})\Big)\bigg(\frac{g}{1+g}a_2p_2^{-n_2}\bigg) \\
&+\Big(p_3-(c+c^{'})\Big)\bigg(\frac{g}{1+g}a_3p_3^{-n_3}\bigg) - (G+G^{'})g.
\end{aligned}$$

Decentralised Case

In this case, it is assumed that the retailer is the leader and the manufacturer is the follower. Based on manufacturer's suggested optimal selling price, differentiation of the retailer's profit with respect to p_i, g are as follows:

$$
\begin{aligned}
\frac{\partial\theta_r}{\partial p_i} &= \frac{g}{1+g}a_i p_i^{-n_i} - \frac{g}{1+g}n_i(p_i-s)a_i p_i^{-n_i-1}, \forall i \\
\frac{\partial^2\theta_r}{\partial {p_i}^2} &= -\frac{g}{1+g}a_i p_i^{-n_i-2}n_i((1-n_i)p_i+(n_i+1)s) = X_i, \forall i \\
\frac{\partial\theta_r}{\partial g} &= \left(\frac{1}{1+g}\right)^2 (a_1 p_1^{-n_1}(p_1-s) + a_2 p_2^{-n_2}(p_2-s) + a_3 p_3^{-n_3}(p_3-s)) \\
&\quad -(1-\alpha)(G+G'), \\
\frac{\partial^2\theta_r}{\partial g\partial p_i} &= \frac{\partial^2\theta_r}{\partial p_i \partial g} = \left(\frac{1}{1+g}\right)^2 a_i p_i^{-n_i-1}((1-n_i)p_i+n_i s), \forall i \\
\frac{\partial^2\theta_r}{\partial g^2} &= -\frac{2\Big((p_1-s)a_1 p_1^{-n_1} + (p_2-s)a_2 p_2^{-n_2} + (p_1-s)a_3 p_3^{-n_3}\Big)}{(1+g)^3} < 0 \\
&\quad \text{as } p_1 > s,\ p_2 > s, \text{ and } p_3 > s, \\
\frac{\partial^2\theta_r}{\partial p_1 \partial p_2} &= \frac{\partial^2\theta_r}{\partial p_1 \partial p_3} = \frac{\partial^2\theta_r}{\partial p_2 \partial p_3} = 0.
\end{aligned}
$$

Proposition 3. *The profit function θ_r obtains its maximum value at $(g^*, p_1^*, p_2^*, p_3^*)$ when $p_1^* = \frac{n_1 s}{n_1-1}$, $p_2^* = \frac{n_2 s}{n_2-1}$, $p_3^* = \frac{n_3 s}{n_3-1}$, and $g^* = -1+\sqrt{A}$ where $n_1 > 1$, $n_2 > 1$, $n_3 > 1$ and $A = \frac{1}{(1-\alpha)(G+G')}\left[\frac{a_1 s^{1-n_1} n_1^{-n_1}}{(n_1-1)^{1-n_1}} + \frac{a_2 s^{1-n_2} n_2^{-n_2}}{(n_2-1)^{1-n_2}} + \frac{a_3 s^{1-n_3} n_3^{-n_3}}{(n_3-1)^{1-n_3}}\right]$.*

Proof. $\frac{\partial\theta_r}{\partial p_i} = 0 \rightarrow p_i^* = \frac{n_i s}{n_i-1}$ and $\frac{\partial\theta_r}{\partial g} = 0 \rightarrow g^* = -1+\sqrt{A}$ where $A = \frac{1}{(1-\alpha)(G+G')}$ $\left[\frac{a_1 s^{1-n_1} n_1^{-n_1}}{(n_1-1)^{1-n_1}} + \frac{a_2 s^{1-n_2} n_2^{-n_2}}{(n_2-1)^{1-n_2}} + \frac{a_3 s^{1-n_3} n_3^{-n_3}}{(n_3-1)^{1-n_3}}\right]$. For feasibility, $n > 1$ and $A > 1$ must hold. At $(g^*, p_1^*, p_2^*, p_3^*)$, $\frac{\partial^2\theta_r}{\partial g \partial p_i} = 0$. The Hessian matrix is performed here to prove the concavity globally. $|H_{11}| = -X_1 < 0, |H_{22}| = X_1 X_2 > 0, |H_{33}| = -X_1 X_2 X_3 < 0$, and $|H_{44}| = 2a_1 a_2 a_3 g^3 s(\frac{n_1 s}{n_1-1})^{-1-2n_1}(\frac{n_2 s}{n_2-1})^{-1-2n_2}(\frac{n_3 s}{n_3-1})^{-1-2n_3}$
$\times \Bigg[a_1(n_2-1)(n_3-1)(\frac{n_2 s}{n_2-1})^{n_2}(\frac{n_3 s}{n_3-1})^{n_3} + a_2(n_1-1)(n_3-1)(\frac{n_1 s}{n_1-1})^{n_1}(\frac{n_3 s}{n_3-1})^{n_3} + a_3(n_1-1)(n_2-1)(\frac{n_1 s}{n_1-1})^{n_1}(\frac{n_2 s}{n_2-1})^{n_2}\Bigg] > 0$ as $n_1 > 1, n_2 > 1, n_3 > 1$. Hence the Proof. □

Here manufacturer is considered a follower. Hence the manufacturer's profit is $\theta_m = \left(s-(c+c')\right)\left(\frac{g}{1+g}a_1 p_1^{-n_1}\right) + \left(s-(c+c')\right)\left(\frac{g}{1+g}a_2 p_2^{-n_2}\right) + \left(s-(c+c')\right)\left(\frac{g}{1+g}a_3 p_3^{-n_3}\right) - \alpha(G+G')g$ at $(g^*, p_1^*, p_2^*, p_3^*)$.

Centralised Case

In this case, the manufacturer and retailer jointly decide and find the optimum values for the total profit. Differentiation of the profit of retailer with respect to p_i, g are as follows:

$$
\begin{aligned}
\frac{\partial\theta}{\partial p_i} &= \frac{g}{1+g}a_i p_i^{-n_i} - \frac{g}{1+g}n_i(p_i-(c+c'))a_i p_i^{-n_i-1}, \forall i \\
\frac{\partial^2\theta}{\partial {p_i}^2} &= -\frac{g}{1+g}a_i p_i^{-n_i-2} n_i((1-n_i)p_i+(n_i+1)(c+c')) = X_i, \forall i \\
\frac{\partial\theta}{\partial g} &= \left(\frac{1}{1+g}\right)^2 (a_1 p_1^{-n_1}(p_1-(c+c'))+a_2 p_2^{-n_2}(p_2-(c+c'))+a_3 p_3^{-n_3}(p_3-(c+c'))) - (G+G'), \\
\frac{\partial^2\theta}{\partial g\partial p_i} &= \frac{\partial^2\theta}{\partial p_i\partial g} = \left(\frac{1}{1+g}\right)^2 a_i p_i^{-n_i-1}((1-n_i)p_i+n_i(c+c')), \forall i \\
\frac{\partial^2\theta}{\partial g^2} &= -\frac{2\Big((p_1-(c+c'))a_1 p_1^{-n_1}+(p_2-(c+c'))a_2 p_2^{-n_2}+(p_3-(c+c'))a_3 p_3^{-n_3}\Big)}{(1+g)^3} = X_4 < 0 \\
& \text{as } p_1 > s,\ p_2 > s, \text{ and } p_3 > s, \\
\frac{\partial^2\theta}{\partial p_1\partial p_2} &= \frac{\partial^2\theta}{\partial p_1\partial p_3} = \frac{\partial^2\theta}{\partial p_2\partial p_3} = 0.
\end{aligned}
$$

Proposition 4. *The profit function θ obtains its maximum value at $(g^*, p_1^*, p_2^*, p_3^*)$ when $p_1^* = \frac{n_1(c+c')}{n_1-1}$, $p_2^* = \frac{n_2(c+c')}{n_2-1}$, $p_3^* = \frac{n_3(c+c')}{n_3-1}$, and $g^* = -1+\sqrt{A}$ where $n_1 > 1$, $n_2 > 1$, $n_3 > 1$ and $A = \frac{1}{(G+G')}\left[\frac{a_1(c+c')^{1-n_1}n_1^{-n_1}}{(n_1-1)^{1-n_1}} + \frac{a_2(c+c')^{1-n_2}n_2^{-n_2}}{(n_2-1)^{1-n_2}} + \frac{a_3(c+c')^{1-n_3}n_3^{-n_3}}{(n_3-1)^{1-n_3}}\right]$.*

Proof. $\frac{\partial\theta}{\partial p_i} = 0 \to p_i^* = \frac{n_i(c+c')}{n_i-1}$ and $\frac{\partial\theta}{\partial g} = 0 \to g^* = -1+\sqrt{A}$ where $A = \frac{1}{(G+G')}\left[\frac{a_1(c+c')^{1-n_1}n_1^{-n_1}}{(n_1-1)^{1-n_1}} + \frac{a_2(c+c')^{1-n_2}n_2^{-n_2}}{(n_2-1)^{1-n_2}} + \frac{a_3(c+c')^{1-n_3}n_3^{-n_3}}{(n_3-1)^{1-n_3}}\right]$. For feasibility, $n > 1$ and $A > 1$ must hold. At $(g^*, p_1^*, p_2^*, p_3^*)$, $\frac{\partial^2\theta}{\partial g\partial p_i} = 0$. The Hessian matrix is performed here to prove the concavity globally. $|H_{11}| = -X_1 < 0, |H_{22}| = X_1X_2 > 0, |H_{33}| = -X_1X_2X_3 < 0$, and $|H_{44}| = 2a_1a_2a_3g^3(c+c')(\frac{n_1(c+c')}{n_1-1})^{-1-2n_1}(\frac{n_2(c+c')}{n_2-1})^{-1-2n_2}(\frac{n_3(c+c')}{n_3-1})^{-1-2n_3}$ $\times\Big[a_1(n_2-1)(n_3-1)(\frac{n_2(c+c')}{n_2-1})^{n_2}(\frac{n_3(c+c')}{n_3-1})^{n_3} + a_2(n_1-1)(n_3-1)(\frac{n_1(c+c')}{n_1-1})^{n_1}(\frac{n_3(c+c')}{n_3-1})^{n_3}$ $+ a_3(n_1-1)(n_2-1)(\frac{n_1(c+c')}{n_1-1})^{n_1}(\frac{n_2(c+c')}{n_2-1})^{n_2}\Big] > 0$ as $n_1 > 1$, $n_2 > 1$, $n_3 > 1$. Hence the Proof. □

4.2. Model 2: M1 and M2 Competes with Selling Price

In this model, M1 and M2 produce EFP and CP under renewable energy consumption, respectively, which are substitutable types. This case is the competition between EFP and CP in the market. The demand depends on the selling price of both items and the GQ of the product. The greenness is the main feature competing with the CP. Renewable energy has been used for procurement costs and the development of green quality. Hence, the demand of M1 (d_g) and M2 (d_n) are given below. Figure 2 shows the graphical representation of Model 2 and the research process.

$$
\begin{aligned}
d_g(g, p_{1g}, p_{2g}, p_{3g}, p_{1n}, p_{2n}, p_{3n}) &= \left(\frac{g}{1+g}\right)(a_1+a_2+a_3) - b_{1g}p_{1g} \\
&+ b_{1n}p_{1n} - b_{2g}p_{2g} + b_{2n}p_{2n} - b_{3g}p_{3g} + b_{3n}p_{3n} \\
d_n(g, p_{1g}, p_{2g}, p_{3g}, p_{1n}, p_{2n}, p_{3n}) &= \left(\frac{1}{1+g}\right)(a_1+a_2+a_3) - b_{1n}p_{1n} + b_{1g}p_{1g} \\
&- b_{2n}p_{2n} + b_{2g}p_{2g} - b_{3n}p_{3n} + b_{3g}p_{3g}.
\end{aligned}
$$

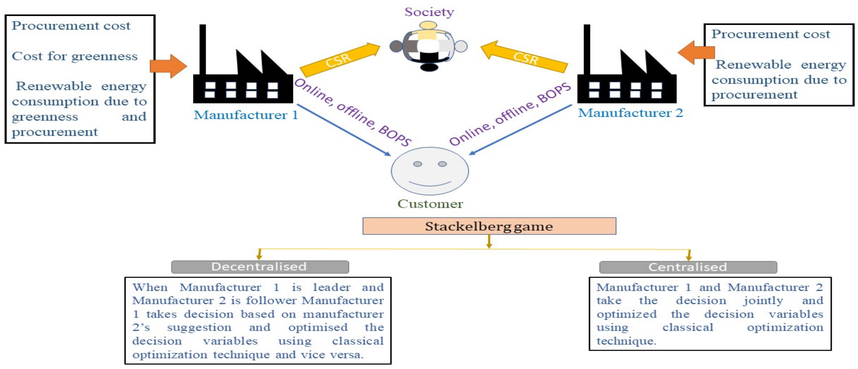

Figure 2. Graphical representation of Model 2 and research process.

It is assumed that the manufacturers share some percentage of profit the society for development through CSR. M1 has two types of costs due to renewable energy. One is for production and the other is for the development of EFP. M2 has an energy cost due to procurement. The profit of M1 (θ_g) and M2 (θ_n) are as follows:

$$
\begin{aligned}
\theta_g(g, p_{1g}, p_{2g}, p_{3g}, p_{1n}, p_{2n}, p_{3n}|\alpha) &= \alpha_0\Big[\text{Selling price} - \text{procurement cost} - \text{energy cost due to} \\
&\quad \text{procurement} - \text{cost for greenness} - \text{energy cost for greenness}\Big] \\
&= \alpha_0\bigg[\Big(p_{1g} - (c_g + c_g^{'})\Big)\bigg(\frac{ga_1}{1+g} - b_{1g}p_{1g} + b_{1n}p_{1n}\bigg) \\
&+ \Big(p_{2g} - (c_g + c_g^{'})\Big)\bigg(\frac{ga_2}{1+g} - b_{2g}p_{2g} + b_{2n}p_{2n}\bigg) \\
&+ \Big(p_{2g} - (c_g + c_g^{'})\Big)\bigg(\frac{ga_3}{1+g} - b_{3g}p_{3g} + b_{3n}p_{3n}\bigg) - (G + G^{'})g\bigg] \\
\theta_n(g, p_{1g}, p_{2g}, p_{3g}, p_{1n}, p_{2n}, p_{3n}|\beta) &= \beta_0\Big[\text{Selling price} - \text{procurement cost} - \text{energy cost due to procurement}\Big] \\
&= \beta_0\bigg[\Big(p_{1n} - (c_n + c_n^{'})\Big)\bigg(\frac{ga_1}{1+g} + b_{1g}p_{1g} - b_{1n}p_{1n}\bigg) \\
&+ \Big(p_{2n} - (c_n + c_n^{'})\Big)\bigg(\frac{ga_2}{1+g} + b_{2g}p_{2g} - b_{2n}p_{2n}\bigg) \\
&+ \Big(p_{2n} - (c_n + c_n^{'})\Big)\bigg(\frac{ga_3}{1+g} + b_{3g}p_{3g} - b_{3n}p_{3n}\bigg)\bigg]
\end{aligned}
$$

where $1 - \alpha = \alpha_0, 1 - \beta = \beta_0$.

4.2.1. When M1 Knows the Fixed Selling Price of CP

In this case, M2 has no option to change the selling price of the CP, and M1 is a monopolist. M1 gets the profit value by maximizing the profit function θ_g by determining the optimal values of p_{1g}, p_{2g}, p_{3g}, and g.

$$
\begin{aligned}
\frac{\partial\theta_g}{\partial p_{ig}} &= \alpha_0\bigg[\frac{g}{1+g}a_i - 2b_{ig}p_{ig} + b_{ig}(c_g + c_g^{'}) + b_{in}p_{in}\bigg], \forall i \\
\frac{\partial\theta_g}{\partial g} &= \alpha_0\bigg[\frac{1}{(1+g)^2}\Big[a_1\Big(p_{1g} - (c_g + c_g^{'})\Big) + a_2\Big(p_{2g} - (c_g + c_g^{'})\Big) + a_3\Big(p_{3g} - (c_g + c_g^{'})\Big)\Big] - (G + G^{'})\bigg]
\end{aligned}
$$

For optimum values of θ_g

$$\begin{aligned}
\frac{\partial\theta_g}{\partial p_{ig}} &= 0 \rightarrow p_{ig} = \frac{\frac{g}{1+g}a_i + b_{ig}(c_g + c_g^{'}) + b_{in}p_{in}}{2b_{ig}}, \forall i \\
\frac{\partial\theta_g}{\partial g} &= 0 \rightarrow (1+g)^3 + 3H(1+g) + (G+G^{'}) = 0
\end{aligned}$$

where $H_1 = -\frac{1}{6(G+G')}\Big[\frac{a_1^2}{b_{1g}} + \frac{a_2^2}{b_{2g}} + \frac{a_3^2}{b_{3g}} + \frac{a_1}{b_{1g}}\Big(b_{1n}p_{1n} - b_{1g}(c_g + c_g^{'})\Big) + \frac{a_2}{b_{2g}}(b_{2n}p_{2n} - b_{2g}(c_g + c_g^{'})) + \frac{a_3}{b_{3g}}\Big(b_{3n}p_{3n} - b_{3g}(c_g + c_g^{'})\Big)\Big], G_1 = \frac{1}{2(G+G')}\Big[\frac{a_1^2}{b_{1g}} + \frac{a_2^2}{b_{2g}} + \frac{a_3^2}{b_{3g}}\Big].$

The discriminant is

$$\Delta = G_1^2 + 4H_1^3 = \frac{\left[\begin{array}{l} 27b_{1g}b_{2g}b_{3g}(G+G^{'})(a_1^2 b_{2g}b_{3g} + a_2^2 b_{1g}b_{3g} + a_3^2 b_{1g}b_{2g})^2 - 2(a_1 b_{2g}b_{3g}(a_1 - b_{1g}(c_g + c_g^{'}) + b_{1n}p_{1n}) \\ +a_2 b_{1g}b_{3g}(a_2 - b_{2g}(c_g + c_g^{'}) + b_{2n}p_{2n}) + a_3 b_{1g}b_{2g}(a_3 - b_{3g}(c_g + c_g^{'}) + b_{3n}p_{3n}))^3 \end{array}\right]}{108 b_{1g}^3 b_{2g}^3 b_{3g}^3 (G+G')^3}$$

If $H_1 = G_1 = 0$, a feasible solution does not exist. If $H_1 = G_1$ and $a_1 \neq (b_{1g}(c_g + c_g^{'}) - b_{1n}p_{1n})$, $a_2 \neq (b_{2g}(c_g + c_g^{'}) - b_{2n}p_{2n})$, $a_3 \neq (b_{3g}(c_g + c_g^{'}) - b_{3n}p_{3n})$, then there is need for feasibility test of the positive values of g. If $\Delta > 0$, there are three distinct real roots. Positive roots are considered, and optimality conditions are verified in that case. If $\Delta < 0$, if one real value of g is positive, then a feasible solution exists.

Proposition 5. *The profit function θ_g obtains its maximum value at $(g^*, p_{1g}^*, p_{2g}^*, p_{3g}^*)$ if $g^* > \frac{\sum_{i=1}^3\left(\frac{a_i^2}{b_{ig}} + 2a_i(c_g + c_g^{'}) - 2\frac{a_i b_{in}p_{in}}{b_{ig}}\right)}{2\sum_{i=1}^3\left(\frac{a_i^2}{b_{ig}} - a_i(c_g + c_g^{'}) + \frac{a_i b_{in}p_{in}}{b_{ig}}\right)}$ holds, where p_{1n}, p_{2n}, p_{3n} are known.*

Proof. The optimum values are $p_{ig}^* = \frac{\frac{g^*}{1+g^*}a_i + b_{ig}(c_g + c_g^{'}) + b_{in}p_{in}}{2b_{ig}}$ $\forall i$, $(1+g^*)^3 + 3H_1(1+g^*) + G_1 = 0$.

$$\begin{aligned}
\frac{\partial^2\theta_g}{\partial p_{ig}^2} &= -2\alpha_0 b_{ig} < 0, \forall i \\
\frac{\partial^2\theta_g}{\partial g^2} &= -\alpha_0\frac{2}{(1+g)^3}\Big[a_1\Big(p_{1g} - (c_g + c_g^{'})\Big) + a_2\Big(p_{2g} - (c_g + c_g^{'})\Big) + a_3\Big(p_{3g} - (c_g + c_g^{'})\Big)\Big] < 0, \\
& \quad \text{as } p_{1g} > (c_g + c_g^{'}),\ p_{2g} > (c_g + c_g^{'}), \text{ and } p_{3g} > (c_g + c_g^{'}) \\
\frac{\partial^2\theta_g}{\partial p_{ig}\partial g} &= \frac{\partial^2\theta_g}{\partial g\partial p_{ig}} = \frac{\alpha_0 a_i}{(1+g)^2}, \forall i
\end{aligned}$$

The Hessian matrix is performed here to prove the concavity globally. $|H_{11}| = -2\alpha_0 b_{1g} < 0, |H_{22}| = 4\alpha_0^2 b_{1g}b_{2g} > 0, |H_{33}| = -8\alpha_0^3 b_{1g}b_{2g}b_{3g} < 0$, and $|H_{44}| > 0$ if $g^* > \frac{\sum_{i=1}^3\left(\frac{a_i^2}{b_{ig}} + 2a_i(c_g + c_g^{'}) - 2\frac{a_i b_{in}p_{in}}{b_{ig}}\right)}{2\sum_{i=1}^3\left(\frac{a_i^2}{b_{ig}} - a_i(c_g + c_g^{'}) + \frac{a_i b_{in}p_{in}}{b_{ig}}\right)}$ holds, as $p_{1g} > (c_g + c_g^{'})$, $p_{2g} > (c_g + c_g^{'})$, $p_{3g} > (c_g + c_g^{'})$.

Hence the Proof. □

4.2.2. When M2 Knows the Fixed Selling Price of EFP and GQ

In this case, M1 fixes the selling price of the EFP, and M2 can change the selling price of CP. M2 gets the profit value by maximizing the profit function θ_n by determining the optimal values of p_{1n}, p_{2n}, and p_{3n}.

$$\frac{\partial\theta_n}{\partial p_{in}} = \beta_0\left[\frac{1}{1+g}a_i + b_{ig}p_{ig} + b_{in}(c_n + c_n^{'}) - 2b_{in}p_{in}\right], \forall i$$

$$\frac{\partial\theta_n}{\partial p_{in}} = 0 \to p_{in} = \frac{\frac{1}{1+g}a_i + b_{in}(c_n + c_n^{'}) + b_{ig}p_{ig}}{2b_{in}}, \forall i$$

Proposition 6. *θ_n obtains at the maximum value at $(p_{1n}{}^*, p_{2n}{}^*, p_{3n}{}^*)$ for known values of $(p_{1g}$, p_{2g}, p_{3g}, $g)$.*

Proof.

$$\frac{\partial^2\theta_n}{\partial p_{in}^2} = -2\beta_0 b_{in} < 0, \forall i$$

The Hessian matrix is performed here to prove the concavity globally. $|H_{11}| = -2\beta_0 b_{1n} < 0$, $|H_{22}| = 4\beta_0{}^2 b_{1n}b_{2n} > 0$, $|H_{33}| = -8\beta_0{}^3 b_{1n}b_{2n}b_{3n} < 0$ at $p_{1n}^* = \frac{\frac{1}{1+g}a_1 + b_{1n}(c_n + c_n^{'}) + b_{1g}p_{1g}}{2b_{1n}}$, $p_{2n}^* = \frac{\frac{1}{1+g}a_2 + b_{2n}(c_n + c_n^{'}) + b_{2g}p_{2g}}{2b_{2n}}$, $p_{3n}^* = \frac{\frac{1}{1+g}a_3 + b_{3n}(c_n + c_n^{'}) + b_{3g}p_{3g}}{2b_{3n}}$. Hence the proof. □

4.3. Pricing Analysis in Co-Ordinated System of M1 and M2

In this case, M1 and M2 jointly make decisions on the decision variables. The coordinated system's total profit is

$$\begin{aligned}
&\theta(g, p_{1g}, p_{2g}, p_{3g}, p_{1n}, p_{2n}, p_{3n}|\alpha, \beta) \\
&= \alpha_0\bigg[\Big(p_{1g} - (c_g + c_g^{'})\Big)\Big(\frac{g}{1+g}a_1 - b_{1g}p_{1g} + b_{1n}p_{1n}\Big) \\
&+\Big(p_{2g} - (c_g + c_g^{'})\Big)\Big(\frac{g}{1+g}a_2 - b_{2g}p_{2g} + b_{2n}p_{2n}\Big) \\
&+\Big(p_{3g} - (c_g + c_g^{'})\Big)\Big(\frac{g}{1+g}a_3 - b_{3g}p_{3g} + b_{3n}p_{3n}\Big) - g(G + G^{'})\bigg] \\
&+\beta_0\bigg[\Big(p_{1n} - (c_n + c_n^{'})\Big)\Big(\frac{1}{1+g}a_1 + b_{1g}p_{1g} - b_{1n}p_{1n}\Big) \\
&+\Big(p_{2n} - (c_n + c_n^{'})\Big)\Big(\frac{1}{1+g}a_2 + b_{2g}p_{2g} - b_{2n}p_{2n}\Big) \\
&+\Big(p_{3n} - (c_n + c_n^{'})\Big)\Big(\frac{1}{1+g}a_3 + b_{3g}p_{3g} - b_{3n}p_{3n}\Big)\bigg].
\end{aligned}$$

To obtain optimum values, differentiation of θ with respect to $p_{1g}, p_{2g}, p_{3g}, p_{1n}, p_{2n}, p_{3n}, g$ are as follows:

$$\begin{aligned}
\frac{\partial\theta}{\partial g} &= \alpha_0\bigg[\frac{1}{(1+g)^2}\Big(a_1\Big(p_{1g} - (c_g + c_g^{'})\Big) + a_2\Big(p_{2g} - (c_g + c_g^{'})\Big) + a_3\Big(p_{3g} - (c_g + c_g^{'})\Big)\Big) \\
&- (G + G^{'})\bigg] - \beta_0\bigg[\frac{1}{(1+g)^2}\Big(a_1\Big(p_{1n} - (c_n + c_n^{'})\Big) + a_2\Big(p_{2n} - (c_n + c_n^{'})\Big) \\
&+ a_3\Big(p_{3n} - (c_n + c_n^{'})\Big)\Big)\bigg]
\end{aligned}$$

$$
\begin{aligned}
\frac{\partial\theta}{\partial p_{ig}} &= \alpha_0\left[\frac{g}{1+g}a_i - 2b_{ig}p_{ig} + b_{in}p_{in} + b_{ig}(c_g + c_g^{'})\right] + \beta_0 b_{ig}\left(p_{in} - (c_n + c_n^{'})\right), \forall i \\
\frac{\partial\theta}{\partial p_{in}} &= \beta_0\left[\frac{1}{1+g}a_i - 2b_{in}p_{in} + b_{ig}p_{ig} + b_{in}(c_n + c_n^{'})\right] + \alpha_0 b_{in}\left(p_{ig} - (c_g + c_g^{'})\right), \forall i \\
\frac{\partial^2\theta}{\partial p_{ig}\partial p_{jg}} &= \frac{\partial^2\theta_g}{\partial p_{in}\partial p_{jn}} = \frac{\partial^2\theta}{\partial p_{ig}\partial p_{jn}} = 0 \; (i \neq j) \\
\frac{\partial^2\theta}{\partial p_{ig}^2} &= -2\alpha_0 b_{ig} < 0, \forall i \\
\frac{\partial^2\theta}{\partial p_{in}^2} &= -2\beta_0 b_{in} < 0, \forall i \\
\frac{\partial^2\theta}{\partial p_{ig}\partial p_{in}} &= (1+\alpha)b_{in} + (1+\beta)b_{ig}, \forall i \\
\frac{\partial^2\theta}{\partial g^2} &= -\alpha_0\frac{2}{(1+g)^3}\left[a_1\left(p_{1g} - (c_g + c_g^{'})\right) + a_2\left(p_{2g} - (c_g + c_g^{'})\right) + a_3\left(p_{3g} - (c_g + c_g^{'})\right)\right] \\
&+ \beta_0\frac{2}{(1+g)^3}\left[a_1\left(p_{1n} - (c_n + c_n^{'})\right) + a_2\left(p_{2n} - (c_n + c_n^{'})\right) + a_3\left(p_{3n} - (c_n + c_n^{'})\right)\right]
\end{aligned}
$$

From $\frac{\partial\theta}{\partial p_{ig}} = 0$ and $\frac{\partial\theta}{\partial p_{in}} = 0$, the following are obtained: $p_{ig}^* = \frac{2b_{in}\beta_0\theta_i(g) + [b_{in}\alpha_0 + b_{ig}\beta_0]\theta_{ii}(g)}{[b_{in}\alpha_0 - b_{ig}\beta_0]^2}$, and $p_{in}^* = \frac{2b_{ig}\alpha_0\theta_{ii}(g) + [b_{in}\alpha_0 + b_{ig}\beta_0]\theta_i(g)}{[b_{in}\alpha_0 - b_{ig}\beta_0]^2}$, where $\theta_i(g) = -\alpha_0\left[\frac{a_i g}{1+g} + b_{ig}(c_g + c_g^{'})\right] + \beta_0 b_{ig}(c_n + c_n^{'})$ and $\theta_{ii}(g) = -\beta_0\left[\frac{a_i}{1+g} + b_{in}(c_n + c_n^{'})\right] + \alpha_0 b_{in}(c_g + c_g^{'})$. Putting the values of $p_{1g}^*, p_{2g}^*, p_{3g}^*, p_{1n}^*, p_{2n}^*, p_{3n}^* in \frac{\partial\theta}{\partial g} = 0$, it is obtained that $(1+g)^3 - H(1+g) = 0$ where $H = \frac{\beta_0}{(G+G^{'})\alpha_0}\left[\frac{a_1^2}{b_{1g}\beta_0 - b_{1n}\alpha_0} + \frac{a_2^2}{b_{2g}\beta_0 - b_{2n}\alpha_0} + \frac{a_3^2}{b_{3g}\beta_0 - b_{3n}\alpha_0}\right]$. The model is feasible if $g \neq 0$ and $g \neq -1 - \sqrt{H}$. That means the solution exists if $g = -1 + \sqrt{H}$ where $H > 1$. $(1+g^*)^3 - H(1+g^*) = 0$

Proposition 7. *The profit of the integrated system has a saddle point at* $\left(p_{1g}^*, p_{2g}^*, p_{3g}^*, p_{1n}^*, p_{2n}^*, p_{3n}^*, g^*\right)$ *if* $H > 1$,$b_{1g}\beta_0 \neq b_{1n}\alpha_0$, $b_{2g}\beta_0 \neq b_{2n}\alpha_0$, $b_{3g}\beta_0 \neq b_{3n}\alpha_0$.

Proof. Equating the first-order partial differential equation of the total joint profit with zero, the following is obtained

$$
\begin{aligned}
g^* &= -1 + \sqrt{H} \\
p_{ig}^* &= \frac{2b_{in}\beta_0\theta_i(g) + [b_{in}\alpha_0 + b_{ig}\beta_0]\theta_{ii}(g)}{[b_{in}\alpha_0 - b_{ig}\beta_0]^2} \\
p_{in}^* &= \frac{2b_{ig}\alpha_0\theta_{ii}(g) + [b_{in}\alpha_0 + b_{ig}\beta_0]\theta_i(g)}{[b_{in}\alpha_0 - b_{ig}\beta_0]^2}
\end{aligned}
$$

The hessian matrix at $(p_{1g}^*, p_{2g}^*, p_{3g}^*, p_{1n}^*, p_{2n}^*, p_{3n}^*, g^*)$ is J =

$$\begin{vmatrix} \partial^2_{p^2_{1g}}\theta(\cdot) & \partial^2_{p_{1g}p_{2g}}\theta(\cdot) & \partial^2_{p_{1g}p_{3g}}\theta(\cdot) & \partial^2_{p_{1g}p_{1n}}\theta(\cdot) & \partial^2_{p_{1g}p_{2n}}\theta(\cdot) & \partial^2_{p_{1g}p_{3n}}\theta(\cdot) & \partial^2_{p_{1g}g}\theta(\cdot) \\ \partial^2_{p_{2g}p_{1g}}\theta(\cdot) & \partial^2_{p^2_{2g}}\theta(\cdot) & \partial^2_{p_{2g}p_{3g}}\theta(\cdot) & \partial^2_{p_{2g}p_{1n}}\theta(\cdot) & \partial^2_{p_{2g}p_{2n}}\theta(\cdot) & \partial^2_{p_{2g}p_{3n}}\theta(\cdot) & \partial^2_{p_{2g}g}\theta(\cdot) \\ \partial^2_{p_{3g}p_{1g}}\theta(\cdot) & \partial^2_{p_{3g}p_{2g}}\theta(\cdot) & \partial^2_{p^2_{3g}}\theta(\cdot) & \partial^2_{p_{3g}p_{1n}}\theta(\cdot) & \partial^2_{p_{3g}p_{2n}}\theta(\cdot) & \partial^2_{p_{3g}p_{3n}}\theta(\cdot) & \partial^2_{p_{3g}g}\theta(\cdot) \\ \partial^2_{p_{1n}p_{1g}}\theta(\cdot) & \partial^2_{p_{1n}p_{2g}}\theta(\cdot) & \partial^2_{p_{1n}p_{3g}}\theta(\cdot) & \partial^2_{p^2_{1n}}\theta(\cdot) & \partial^2_{p_{1n}p_{2n}}\theta(\cdot) & \partial^2_{p_{1n}p_{3n}}\theta(\cdot) & \partial^2_{p_{1n}g}\theta(\cdot) \\ \partial^2_{p_{2n}p_{1g}}\theta(\cdot) & \partial^2_{p_{2n}p_{2g}}\theta(\cdot) & \partial^2_{p_{2n}p_{3g}}\theta(\cdot) & \partial^2_{p_{2n}p_{1n}}\theta(\cdot) & \partial^2_{p^2_{2n}}\theta(\cdot) & \partial^2_{p_{2n}p_{3n}}\theta(\cdot) & \partial^2_{p_{2n}g}\theta(\cdot) \\ \partial^2_{p_{3n}p_{1g}}\theta(\cdot) & \partial^2_{p_{3n}p_{2g}}\theta(\cdot) & \partial^2_{p_{3n}p_{3g}}\theta(\cdot) & \partial^2_{p_{3n}p_{1n}}\theta(\cdot) & \partial^2_{p_{3n}p_{2n}}\theta(\cdot) & \partial^2_{p^2_{3n}}\theta(\cdot) & \partial^2_{p_{3n}g}\theta(\cdot) \\ \partial^2_{gp_{1g}}\theta(\cdot) & \partial^2_{gp_{2g}}\theta(\cdot) & \partial^2_{gp_{3g}}\theta(\cdot) & \partial^2_{gp_{1n}}\theta(\cdot) & \partial^2_{gp_{2n}}\theta(\cdot) & \partial^2_{gp_{3n}}\theta(\cdot) & \partial^2_{g^2}\theta(\cdot) \end{vmatrix}$$

$|H_{11}| = -2\alpha_0 b_{1g} < 0$, $|H_{22}| = 4\alpha_0^2 b_{1g}b_{2g} > 0$, $|H_{33}| = -8\alpha_0^3 b_{1g}b_{2g}b_{3g} < 0$, $|H_{44}| = -4\alpha_0^2 b_{2g}b_{3g}(b_{1g}\beta_0 - b_{1n}\alpha_0)^2 < 0$, $|H_{55}| = -2\alpha_0 b_{3g}(b_{1g}\beta_0 - b_{1n}\alpha_0)^2(b_{2g}\beta_0 - b_{2n}\alpha_0)^2 < 0$, $|H_{66}| = -(b_{1g}\beta_0 - b_{1n}\alpha_0)^2(b_{2g}\beta_0 - b_{2n}\alpha_0)^2(b_{3g}\beta_0 - b_{3n}\alpha_0)^2 < 0$, $|H_{77}| = \frac{2}{(1+g)^3}(b_{1g}\beta_0 - b_{1n}\alpha_0)^2(b_{2g}\beta_0 - b_{2n}\alpha_0)^2(b_{3g}\beta_0 - b_{3n}\alpha_0)^2\big((a_1(p_{1g} - (c_g + c_g^{'}))\alpha_0 - (p_{1n} - (c_n + c_n^{'}))(1-\delta)) + (a_2(p_{2g} - (c_g + c_g^{'}))\alpha_0 - (p_{2n} - (c_n + c_n^{'}))(1-\delta)) + (a_3(p_{3g} - (c_g + c_g^{'}))\alpha_0 - (p_{3n} - (c_n + c_n^{'}))(1-\delta))\big)$. Hence the proof. From this, the following proposition arrives. □

Proposition 8. *The profit of the integrated system (θ) is inconclusive if $H > 1$, $b_{1g}\beta_0 = b_{1n}\alpha_0$, $b_{2g}\beta_0 = b_{2n}\alpha_0$, $b_{3g}\beta_0 = b_{3n}\alpha_0$, $|H_{77}| < 0$, and $(p_{1g}^*, p_{2g}^*, p_{3g}^*, p_{1n}^*, p_{2n}^*, p_{3n}^*)$ is not both finite. Therefore, it is seen that M1 and M2 can not simultaneously obtain the optimal price. In that case, M1 and M2 both declare the same price of the product, which means, $(p_{1g}^* = p_{1n}^*)$, $(p_{2g}^* = p_{2n}^*)$, $(p_{3g}^* = p_{3n}^*)$ and M1 fix the GQ g of the product by solving*

$$\alpha_0\left[\frac{1}{(1+g)^2}\left(a_1\left(p_{1g} - (c_g + c_g^{'})\right) + a_2\left(p_{2g} - (c_g + c_g^{'})\right) + a_3\left(p_{3g} - (c_g + c_g^{'})\right)\right) - (G + G^{'})\right] - \beta_0\left[\frac{1}{(1+g)^2}\left(a_1\left(p_{1n} - (c_n + c_n^{'})\right) + a_2\left(p_{2n} - (c_n + c_n^{'})\right) + a_3\left(p_{3n} - (c_n + c_n^{'})\right)\right)\right] = 0.$$

$$g = -1 + \frac{\sqrt{\begin{array}{l}\alpha_0(G+G^{'})\big(a_1\alpha_0((c_g + c_g^{'}) - p_{1g}) + a_1\beta_0((c_n + c_n^{'}) - p_{1n}) + a_2\alpha_0((c_g + c_g^{'}) - p_{2g}) \\ +a_2\beta_0((c_n + c_n^{'}) - p_{1n}) + a_3\alpha_0((c_g + c_g^{'}) - p_{3g}) + a_3\beta_0((c_n + c_n^{'}) - p_{1n})\big)\end{array}}}{\alpha_0(G+G^{'})}$$

This value is the optimum value g^* and θ is concave if $\frac{p_{1g} - (c_g + c_g^{'})}{p_{1n} - (c_n + c_n^{'})} > \frac{\beta_0}{\alpha_0}$, $\frac{p_{2g} - (c_g + c_g^{'})}{p_{2n} - (c_n + c_n^{'})} > \frac{\beta_0}{\alpha_0}$, $\frac{p_{3g} - (c_g + c_g^{'})}{p_{3n} - (c_n + c_n^{'})} > \frac{\beta_0}{\alpha_0}$.

4.4. When Demand Is Power Function of Selling Price

In this case, M2 has no option to change the selling price of the CP, and M1 is a monopolist. M1 gets the profit value by maximizing the profit function θ_g by determining the optimal values of p_{1g}, p_{2g}, p_{3g} and g. The demand of M1 (d_g) and M2 (d_g) are as follows:

$$d_g(g, p_{1g}, p_{2g}, p_{3g}, p_{1n}, p_{2n}, p_{3n}) = \left(\frac{g}{1+g}\right)\left(a_1 p_{1g}^{-n_1} p_{1n}^{m_1} + a_2 p_{2g}^{-n_2} p_{2n}^{m_2} + a_3 p_{3g}^{-n_3} p_{3n}^{m_3}\right)$$

and

$$d_n(g, p_{1g}, p_{2g}, p_{3g}, p_{1n}, p_{2n}, p_{3n}) = \left(\frac{1}{1+g}\right)\left(a_1 p_{1g}^{l_1} p_{1n}^{-k_1} + a_2 p_{2g}^{l_2} p_{2n}^{-k_2} + a_3 p_{3g}^{l_3} p_{3n}^{-k_3}\right)$$

respectively. The profit of M1 (θ_g) and M2 (θ_g) are as follows:

$$
\begin{aligned}
&\theta_g(g, p_{1g}, p_{2g}, p_{3g}, p_{1n}, p_{2n}, p_{3n}|\alpha) \\
&= (\alpha_0)\Big[\text{Selling price - procurement cost - energy cost due to procurement - cost for greenness} \\
&- \text{energy cost for greenness}\Big] \\
&= (\alpha_0)\left[\frac{g}{1+g}((p_{1g} - (c_g + c_g^{'}))a_1 p_{1g}^{-n_1} p_{1n}^{m_1} + (p_{2g} - (c_g + c_g^{'}))a_2 p_{2g}^{-n_2} p_{2n}^{m_2}\right. \\
&\left. +(p_{3g} - (c_g + c_g^{'}))a_3 p_{3g}^{-n_3} p_{3n}^{m_3}) - (G + G^{'})g\right]
\end{aligned}
$$

and

$$
\begin{aligned}
&\theta_n(g, p_{1g}, p_{2g}, p_{3g}, p_{1n}, p_{2n}, p_{3n}|\beta) \\
&= (\beta_0)\Big[\text{Selling price - procurement cost - energy cost due to procurement}\Big] \\
&= \frac{(\beta_0)}{1+g}\left[(p_{1n} - (c_n + c_n^{'}))a_1 p_{1g}^{l_1} p_{1n}^{-k_1} + (p_{2n} - (c_n + c_n^{'}))a_2 p_{2g}^{l_2} p_{2n}^{-k_2} + (p_{3n} - (c_n + c_n^{'}))a_3 p_{3g}^{l_3} p_{3n}^{-k_3}\right]
\end{aligned}
$$

When p_{1n}, p_{2n}, p_{3n} are fixed,

$$
\begin{aligned}
\frac{\partial \theta_g}{\partial p_{ig}} &= \alpha_0 \frac{g}{1+g} a_i[(1-n_i)p_{ig}^{-n_i} + n_i(c_g + c_g^{'})p_{ig}^{-n_i-1}]p_{in}^{m_i} \\
\frac{\partial \theta_g}{\partial g} &= \alpha_0\left(\frac{1}{(1+g)^2}[a_1(p_{1g} - (c_g + c_g^{'}))p_{1g}^{-n_1} p_{1n}^{m_1} + a_2(p_{2g} - (c_g + c_g^{'}))p_{2g}^{-n_2} p_{2n}^{m_2}\right. \\
&+ \left. a_3(p_{3g} - (c_g + c_g^{'}))p_{3g}^{-n_3} p_{3n}^{m_3}] - (G + G^{'})\right)
\end{aligned}
$$

From $\frac{\partial \theta_g}{\partial p_{ig}} = 0$ and $\frac{\partial \theta_g}{\partial g} = 0$, the results are $p_{ig}^* = \frac{n_1(c_g + c_g^{'})}{n_1 - 1}, \forall i$, $g^* = -1 + \sqrt{A}$ where $n_1 > 1$, $p_{ig} > (c_g + c_g^{'}) \forall i$, and $A = (\frac{a_1}{(G+G^{'})})(p_{1g} - (c_g + c_g^{'}))p_{1g}^{-n_1} p_{1n}^{m_1} + (\frac{a_2}{(G+G^{'})})(p_{2g} - (c_g + c_g^{'}))p_{2g}^{-n_2} p_{2n}^{m_2} + (\frac{a_3}{(G+G^{'})})(p_{3g} - (c_g + c_g^{'}))p_{3g}^{-n_3} p_{3n}^{m_3}$.

Proposition 9. *The profit function θ_g attains maximum value at $(p_{1g}^*, p_{2g}^*, p_{3g}^*, g^*)$ when $p_{ig}^* = \frac{n_1(c_g + c_g^{'})}{n_1 - 1} \forall i$ and $g^* = -1 + \sqrt{A}$ where $n_1 > 1$, $p_{ig} > (c_g + c_g^{'}) \forall i$ and $A = \frac{a_1}{(G+G^{'})}(p_{1g} - (c_g + c_g^{'}))p_{1g}^{-n_1} p_{1n}^{m_1} + \frac{a_2}{(G+G^{'})}(p_{2g} - (c_g + c_g^{'}))p_{2g}^{-n_2} p_{2n}^{m_2} + \frac{a_3}{(G+G^{'})}(p_{3g} - (c_g + c_g^{'}))p_{3g}^{-n_3} p_{3n}^{m_3}$.*

4.5. Pricing Analysis in Coordinated System of M1 and M2

In this case, M1 and M2 jointly make decisions on the decision variables. The total profit of the coordinated system is as follows:

$$\theta(g, p_{1g}, p_{2g}, p_{3g}, p_{1n}, p_{2n}, p_{3n}|\alpha, \beta)$$
$$= \alpha_0\left[\frac{g}{1+g}((p_{1g}-(c_g+c_g^{'}))a_1p_{1g}^{-n_1}p_{1n}^{m_1}+(p_{2g}-(c_g+c_g^{'}))a_2p_{2g}^{-n_2}p_{2n}^{m_2}\right.$$
$$\left.+(p_{3g}-(c_g+c_g^{'}))a_3p_{3g}^{-n_3}p_{3n}^{m_3})-(G+G^{'})g\right]+\beta_0\left[\frac{1}{1+g}((p_{1n}-(c_n+c_n^{'}))a_1p_{1g}^{l_1}p_{1n}^{-k_1}\right.$$
$$\left.+(p_{2n}-(c_n+c_n^{'}))a_2p_{2g}^{l_2}p_{2n}^{-k_2}+(p_{3n}-(c_n+c_n^{'}))a_3p_{3g}^{l_3}p_{3n}^{-k_3})\right].$$

Differentiation of the integrated system with respect to p_{ig}, p_{in}, g are as follows:

$$\frac{\partial\theta}{\partial p_{ig}} = \alpha_0\frac{g}{1+g}a_i[(1-n_i)p_{ig}^{-n_i}+n_i(c_g+c_g^{'})p_{ig}^{-n_i-1}]p_{in}^{m_i}+\frac{\beta_0}{1+g}a_i[(p_{in}-(c_n+c_n^{'}))l_ip_{ig}^{-l_i-1}p_{in}^{-k_i}]$$
$$\frac{\partial\theta}{\partial p_{in}} = \alpha_0\frac{g}{1+g}a_im_ip_{ig}^{-n_i}p_{in}^{m_i-1}(p_{ig}-(c_g+c_g^{'}))+\frac{\beta_0}{1+g}a_ip_{ig}^{l_i}p_{in}^{-k_i-1}[(1-k_i)p_{in}+k_i(c_n+c_n^{'})]$$
$$\frac{\partial\theta}{\partial g} = \frac{\alpha_0}{(1+g)^2}\left[a_1p_{1g}^{-n_1}p_{1n}^{m_1}(p_{1n}-(c_n+c_n^{'}))+a_2p_{2g}^{-n_2}p_{2n}^{m_2}(p_{2n}-(c_n+c_n^{'}))\right.$$
$$\left.+\ a_3p_{3g}^{-n_3}p_{3n}^{m_3}(p_{3n}-(c_n+c_n^{'}))\right]-\alpha_0(G+G^{'})+\frac{\beta_0}{(1+g)^2}\left[a_1p_{1g}^{l_1}p_{1n}^{-k_1}(p_{1n}-(c_n+c_n^{'}))\right.$$
$$\left.+\ a_2p_{2g}^{l_2}p_{2n}^{-k_2}(p_{2n}-(c_n+c_n^{'}))+a_3p_{3g}^{l_3}p_{3n}^{-k_3}(p_{3n}-(c_n+c_n^{'}))\right]$$

Proposition 10. *The collaborative profit function θ attains its maximum value at $(p_{1g}^*, p_{2g}^*, p_{3g}^*, p_{1n}^*, p_{2n}^*, p_{3n}^*, g^*)$ if the Hessian matrix is negative definite.*

Proof. Equating the derivatives with zero, the optimal solutions are as follows:

$$p_{ig}^* = \frac{(c_g+c_g^{'})(c_n+c_n^{'})(k_in_i-l_im_i)+(c_g+c_g^{'})p_{in}(l_im_i+n_i(1-k_i))}{(p_{in}-(c_n+c_n^{'}))(k_i(1-n_i)+l_im_i)-p_{in}(n_i-1)}$$
$$p_{in}^* = \frac{(c_g+c_g^{'})(c_n+c_n^{'})(k_in_i-l_im_i)+(c_n+c_n^{'})p_{ig}(l_im_i+k_i(1-n_i))}{(p_{ig}-(c_g+c_g^{'}))(n_i(1-k_i)+l_im_i)-p_{ig}(k_i-1)}$$
$$g^* = \frac{\beta_0p_{1g}^{l_1+n_1}p_{1n}^{-k_1-m_1}((c_n+c_n^{'})k_1+p_{1n}(1-k_1))}{m_1(p_{1g}-(c_g+c_g^{'}))\alpha_0}$$

thus, the collaborative profit function θ attains its maximum value at $(p_{1g}^*, p_{2g}^*, p_{3g}^*, p_{1n}^*, p_{2n}^*, p_{3n}^*, g^*)$ if the Hessian matrix is negative definite. And also, the profit of M1 and M2 is obtained. □

5. Numerical Example and Analysis

Example 1. *When the demand function is $d(g, p_1, p_2, p_3) = \frac{g}{1+g}(a_1+a_2+a_3)-b_1p_1-b_2p_2-b_3p_3$ for two-echelon SCM. The input parameters are a_1 = 250, a_2 = 280, a_3 = 270, b_1 = 5, b_2 = 6, b_3 = 4, G = 99, $G^{'}$ = 1; α = 0.4, s = 12, c = 7.9, $c^{'}$ = 0.1.*

When the retailer is performed as the leader and the manufacturer is performed as a follower, the output values are p_1 = 29.46, p_2 = 27.89, p_3 = 37.67, g = 15.20, θ_r = 4762.33, θ_m = 533.27, θ = 5295.61, d = 285.31. The total cost for renewable energy consumption is 84.18 due to greenness.

When the manufacturer and retailer both make a decision jointly, i.e., for a centralized system, the output values are p_1 = 27.08, p_2 = 25.54, p_3 = 35.16, g = 12.05, θ_r = 4659.03, θ_m = 755.55, θ = 5414.57, d = 309.34. The total cost for renewable energy consumption is 85.91 due to greenness and procurement.

From Figure 3, the profit of retailer and manufacturer with respect to GQ has been drawn where it is seen that retailer profit is more than the manufacturer. Figure 4 shows the concavity of the profit with respect to the green quality and online price for the decentralized case. But in the centralized case, the manufacturer can earn more profit than in the decentralized case, and the total system profit is more in the centralized system (Figure 5).

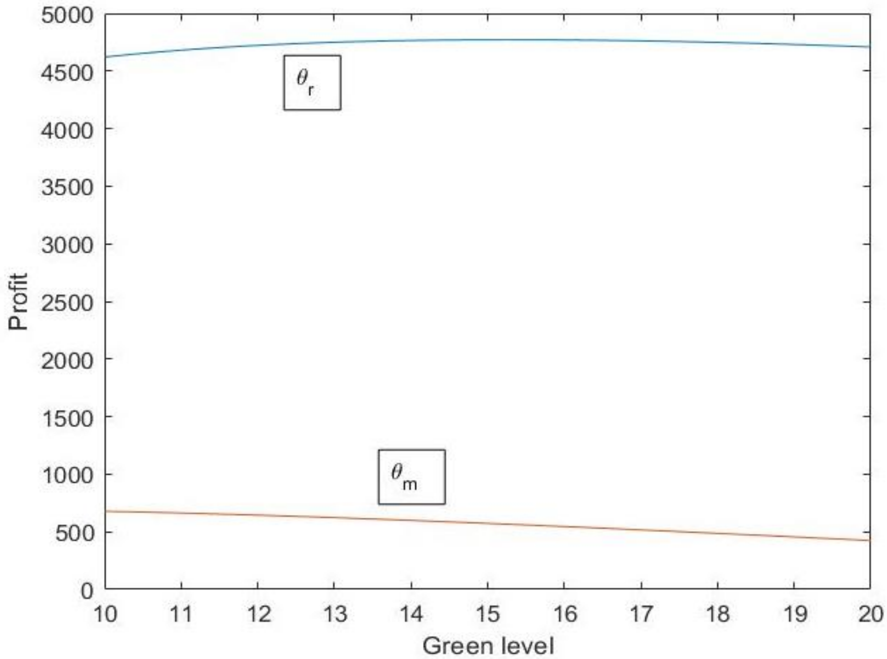

Figure 3. Graphical representation of changes of retailer's and manufacturer's profit with GQ.

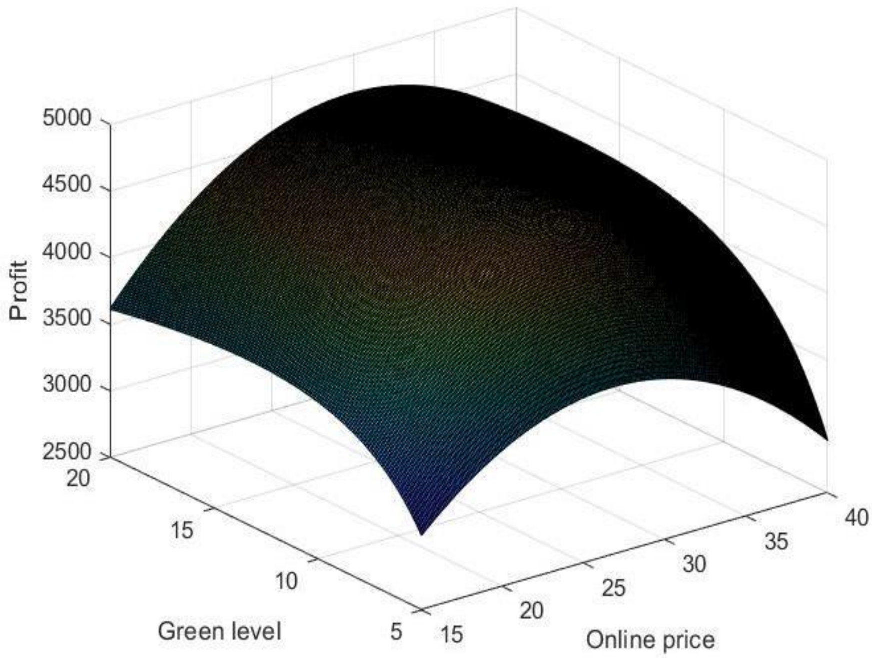

Figure 4. Graphical representation of changes of retailer's profit with GQ and online price.

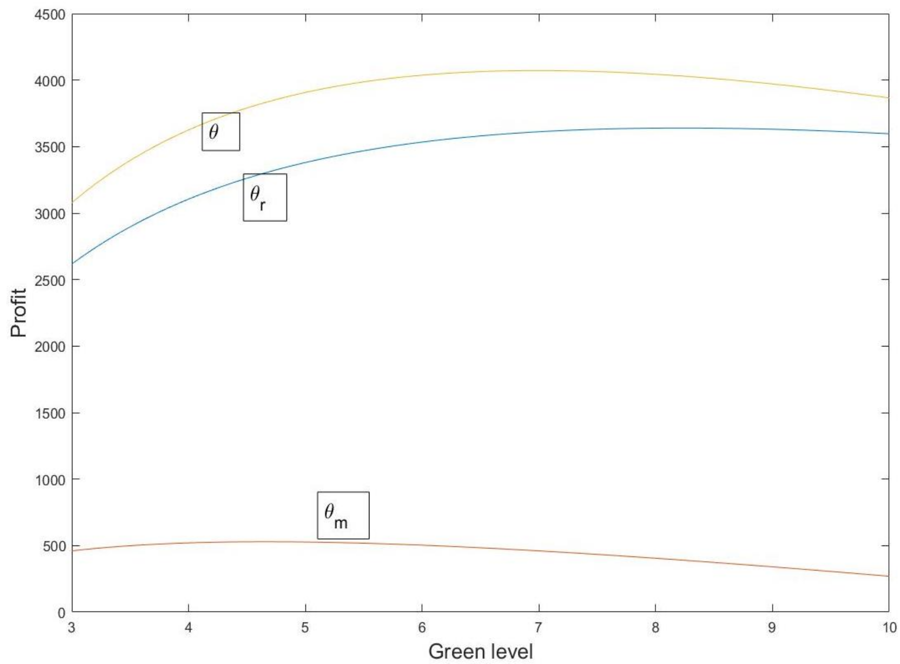

Figure 5. Graphical representation of changes of profit with GQ.

Example 2. *When the demand function is* $D_g(g, p_{1g}, p_{2g}, p_{3g}, p_{1n}, p_{2n}, p_{3n}) = \left(\frac{g}{1+g}\right)\left(a_1 p_{1g}^{-n_1} p_{1n}^{m_1} + a_2 p_{2g}^{-n_2} p_{2n}^{m_2} + a_3 p_{3g}^{-n_3} p_{3n}^{m_3}\right)$ *for two-echelon SCM. The input parameters are* a_1 = *250,000,* a_2 = *280,000,* a_3 = *280,000,* G = *99,* G' = *1,* α = *0.4,* s = *25,* c = *9.9,* c' = *0.1,* n_1 = *1.5,* n_2 = *2,* n_3 = *1.5.*

When the retailer is performed as the leader and the manufacturer is performed as a follower, the output values are p_1 = *75,* p_2 = *50,*p_3 = *75,* g = *25.72,* θ_r = *24,683.51,* θ_m = *12,147.83,* θ = *51,831.34,* d = *878.44. The total cost for renewable energy consumption is 73.28 due to greenness.*

When the manufacturer and retailer both make a decision jointly, i.e., for a centralized system, the output values are p_1 = *30,* p_2 = *20,* p_3 = *30,* g = *25.51,* θ_r = *10,327.53,* θ_m = *54,762.31,* θ = *65,089.84,* d = *3718.85. The total cost for renewable energy consumption is 385.40 due to greenness and procurement. From Figure 6, the profit of the retailer and manufacturer with respect to GQ has been drawn for the centralized case where it is seen that the retailer's profit is less than the manufacturer's.*

Example 3. *When M1 produces EFP and knows the fixed selling price of CP. The input parameters are* a_1 = *250,* a_2 = *280,* a_3 = *270,* b_{1g} = *7,* b_{2g} = *6,* b_{3g} = *8,* b_{1n} = *10,* b_{2n} = *10,* b_{3n} = *17,* G = *99,* G' = *1,* p_{1n} = *30,* p_{2n} = *32,* p_{3n} = *28,* α = *0.05,* β = *0.04,* c_g = *19.9,* c_g' = *0.1,* c_n = *14.9,* c_n' = *0.1. The output values are* p_{1g} = *48.21,* p_{2g} = *58.59,* p_{3g} = *55.61,* g = *15.57,* θ_g = *21,936.89,* θ_n = *11,508.66. The total cost for renewable energy consumption of M1 is 86.96 due to greenness and procurement. If M1 shares 5% of its profit with society, then M1 gets a profit of 21,936.89 after charitable work. If M1 shares 10% of its profit with society, then M1 gets a profit of 20,782.32 after charitable work. If M2 shares 4% of its profit with society then M2 gets a profit of 11,508.66, after charitable work. If M2 shares 10% of its profit with society, then M2 gets a profit of 10,789.37, after charitable work.*

From Figure 6, it is seen that the profit of M2 is concave with CP's online price, whereas the profit of M2 is strictly increasing with CP's online price when the CP's price is known.

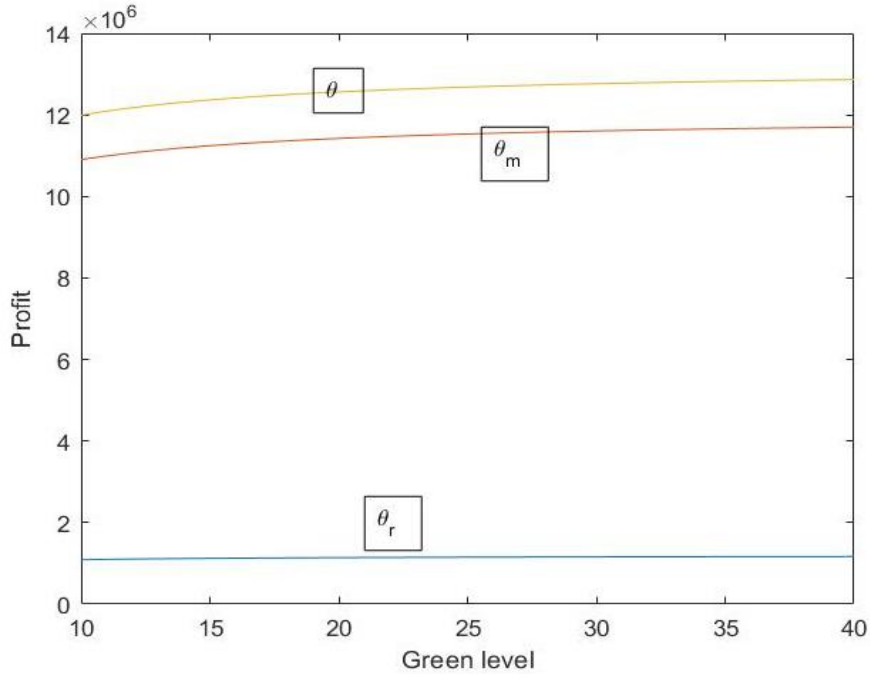

Figure 6. Graphical representation of changes of profit with online price.

Example 4. *When M1 produces EFP and M2 produce CP & both fix the selling price. In this case, the input values are* a_1 *= 250,* a_2 *= 280,* a_3 *= 270,* b_{1g} *= 7,* b_{2g} *= 6,* b_{3g} *= 8,* b_{1n} *= 10,* b_{2n} *= 10,* b_{3n} *= 17, G = 99,* $G^{'}$ *= 1,* $p_{1n} = p_{1g}$ *= 30,* $p_{2n} = p_{2g}$ *= 32,* $p_{3n} = p_{3g}$ *= 28,* α *= 0.05,* β *= 0.04,* c_g *= 17.9,* $c_g^{'}$ *= 0.1,* c_n *= 14.9,* $c_n^{'}$ *= 0.1. The output values are g = 93.99,* θ_g *= 5235.89,* θ_n *= 4887.81,* d_g *= 14,910.73,* d_n *= 5091.46. The total cost for renewable energy consumption of M1 is 220.15 due to greenness and procurement. If M1 shares 5% of its profit with society, then M1 gets a profit of 5235.89, after charitable work. If M1 shares 10% of its profit with society, then M1 gets a profit of 5185.29, after charitable work. The total cost for renewable energy consumption of M2 is 32.16 due to procurement. If M2 shares 4% of its profit with society, then M2 gets a profit of 4887.81, after charitable work. If M2 shares 10% of its profit with society, then M2 gets a profit of 4579.20, after charitable work.*

Example 5. *When M1 produces EFP and M2 produces, CP and demand is the power function of the selling price, and the Manufacturer fixes the selling price of CP. In this case, the input values are* a_1 *= 25,000,* a_2 *= 28,000,* a_3 *= 27,000,* $n_1 = 1.5, n_2 = 2, n_3 = 1.5$*,* $m_1 = 1.5, m_2 = 2, m_3 = 1.5$*, G = 99,* $G^{'}$ *= 1,* α *= 0.05,* β *= 0.04,* $l_1 = 1.5, l_2 = 2, l_3 = 1.5$*,* $k_1 = 1.5, k_2 = 2, k_3 = 1.5$*,* p_{1n} *= 30,* p_{2n} *= 32,* p_{3n} *= 28,* c_g *= 11.9,* $c_g^{'}$ *= 0.1,* c_n *= 9.9,* $c_n^{'}$ *= 0.1. The output values are g = 121.40,* p_{1g} *= 36,* p_{2g} *= 24,* p_{3g} *= 36,* θ_g *= 1,400,180.65,* θ_n *= 13,429.36,* d_g *= 86,602.83,* d_n *= 718.74. The total cost for renewable energy consumption of M1 is 8781.69 due to greenness and procurement. If M1 shares 5% of its profit with society, then M1 gets a profit of 1,400,180.65, after charitable work. If M1 shares 10% of its profit with society, then M1 gets a profit of 1,326,484.94, after charitable work.*

Example 6. *When M1 produces EFP and M2 produces CP, demand is the selling price's power function. For integrated system, the input values are* a_1 *= 25,000,* a_2 *= 28,000,* a_3 *= 27,000,* $n_1 = 1.5, n_2 = 2, n_3 = 1.5$*,* $m_1 = 1.5, m_2 = 2, m_3 = 1.5$*, G = 99,* $G^{'}$ *= 1,* α *= 0.05,* β *= 0.04,* $l_1 = 1.5, l_2 = 2, l_3 = 1.5$*,* $k_1 = 1.5, k_2 = 2, k_3 = 1.5$*,* c_g *= 11.9,* $c_g^{'}$ *= 0.1,* c_n *= 9.9,* $c_g^{'}$ *= 0.1. The output values are* p_{1g} *= 36.66,* p_{2g} *= 24.26,* p_{3g} *= 36.66,* p_{1n} *= 30,* p_{2n} *= 20,* p_{3n} *= 30, g = 168.34,* θ *= 1,111,121.61,* θ_g *= 1,100,822.41,* θ_n *= 10,299.20,* d_g *= 57,189.19,* d_n *= 658.06. If the manufacturers decide that they sell products online only, then the outputs are* p_{1g} *= 36.85,* p_{1n} *= 30.00, g = 132.30,* θ *= 422,608.26,* θ_g *= 417,706.19,* θ_n *= 4,902.06,* d_g *= 18,226.68,* d_n *= 255.32. If the manufacturers decide that they sell products online and offline, then the* *outputs are* $p_{1g} = 36.76$, $p_{2g} = 24.30$, $p_{1n} = 30.00$, $p_{2n} = 20.00$, $g = 146.36$, $\theta = 643{,}937.87$, $\theta_g = 636{,}826.09$, $\theta_n = 7111.78$, $d_g = 37{,}141.67$, $d_n = 510.67$. *The total cost for renewable energy consumption of M1 is 5887.26 due to greenness and procurement. If M1 shares 5% of its profit with society, then M1 gets a profit of 1,100,822.41, after charitable work. If M1 shares 10% of its profit with society, then M1 gets a profit of 1,043,138.47 after charitable work. The total cost for renewable energy consumption of M2 is 65.81, due to procurement. If M2 shares 4 of its profit with society, then M2 gets a profit of 10,299.20 after charitable work. If M2 shares 10 of its profit with society, then M2 gets a profit of 9955.42, after charitable work.*

From Figure 7, the profit of M1, M2, and the integrated system with respect to EFP's online price has been drawn for the centralized case where it is seen that M1 gets more profit than M2.

Comparable table with the model Sana [14] is given in Table 3.

Table 3. Comparative table.

Previous paper	Demand of green product	194.53	Demand of non-green product	14.13
This study	Demand of green product	50619.17	Demand of non-green product	3676.83
Previous paper	Selling price of green product	$39.02	Green level	2.740
This study	Selling price of green product in three channels	$39.34, $25.26, $39.34	Green level	32.38
Previous paper	Selling price of non-green product	$39.34	Total profit	$2370.85
This study	Selling price of non-green product in three channels	$30, $20, $30	Total profit	$118,419.69

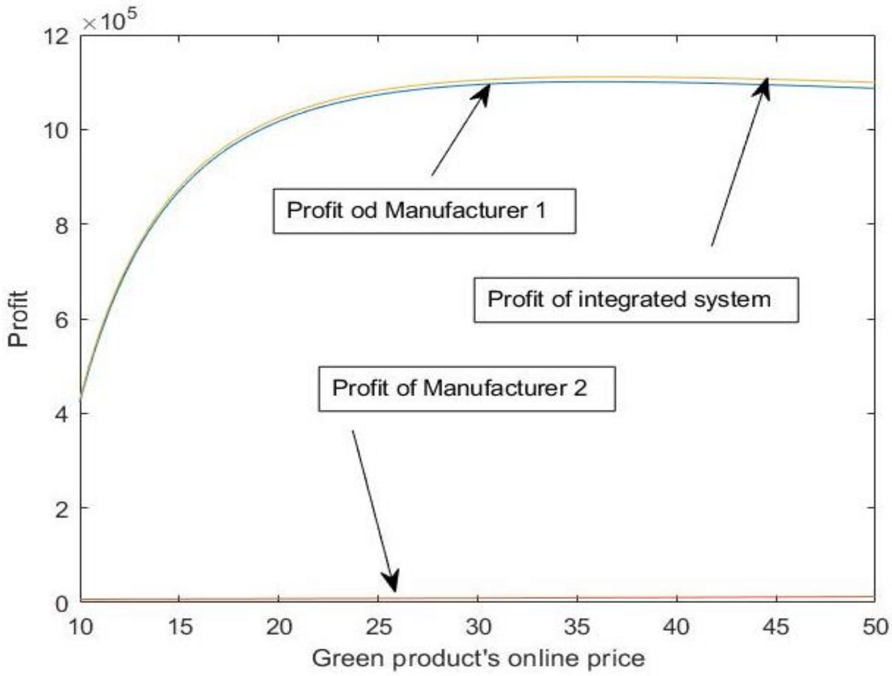

Figure 7. Graphical representation of changes of M1, M2, and integrated system's profit versus GQ.

Discussion

From the result section, it is seen that for all cases, an integrated system under renewable energy always gives the better result, i.e., more profit to the system, and every member gets more benefit from the integrated system rather than the decentralized one system. It is seen that when compared to the cost of CP and EFP, EFP can control the market and keep its reputation for quality products. The result demonstrates that EFP enterprises can control the market while retaining the EFP brand's reputation for standard GQ at a high price compared to CP, with less harmful to the environment under renewable energy consumption. Many businesses frequently scar from creating EFP as the manufacturing cost is high for EFP rather than CP, which increases the selling price of EFP rather than CP. If M1 and M2 fix the same price of EFP and CP, respectively, then also from the result, it is seen that the profit of M1 is more than M2 with GQ and CSR. M1 pays more renewable energy consumption cost to produce EFP than CP but M1 gets more profit than M2. Therefore, there is a responsibility for M1 to know the facts regarding EFP for all people such that customers can buy more EFP and the environment is less harmful. When the demand is a power function of the selling price, the manufacturer producing EFP gains 0.99% more profit than the manufacturer producing the CP. The manufacturer producing EFP sells 0.88% more products than the manufacturer producing the CP. The manufacturers open online and offline channels to sell products, then they lose 0.42% from the original profit. Compared with Sana [14] and this study, this study gives more profit. The previous study gives $2370.85 as profit for the integrated system, whereas this study gives $1,100,822.41 as profit for the integrated system. This is because of the hybrid channel. The previous study considered only one retailing strategy, whereas this study considered three. The demand for the products EFP and CP are also more than in the previous study.

6. Managerial Insights

From Model 1, the main insight is the interaction between the manufacturer and retailer about the customer's EFP shopping habits. M1 motivates other manufacturers as it is eco-friendly and gets more profit than M2. For each case, it is seen that the manufacturer producing EFP products gets more profit than the manufacturer producing CP. Hence, in this study, it was seen that although the manufacturer makes EFP, it gets more profits, motivating many other manufacturers to produce EFP. The demand for EFP is much than the demand for CP. This happens because everyone tries to reduce carbon emissions. That is why, in the marketplace, the demand for green products is larger. From the results section, it is seen that the manufacturers gain 0.62% more profit for the centralized case when they use only online channels. It is advised to the manufacturer to sell the products through three channels to gain more profit. The manufacturer producing EFP sells 0.68% fewer products when only the online channel is considered. Even if the manufacturers decide to sell the products through online channels and offline channels, then also the total profit of the system becomes less than the original system's profit. Therefore, a big managerial insight for the manufacturers is that they should sell products through three different channels.

7. Conclusions

A renewable energy-based model was developed in this study, where the manufacturers were aware of economics, the environment, and society. The manufacturers produced EFP to save the environment, and both manufacturers donate some percentage of profit to society through CSR. Although, in reality, the cost to produce EFP is indeed higher than to produce CP, the government often gives subsidies or rebate taxes for producing EFP to be aware and encourage the customers and manufacturers. Keeping this in mind, a model was established here where the demand for products depended on GQ and the selling price of the product in three different channels. The main findings of this study are as follows: manufacturers must sell their products through hybrid channels as it gives better results and the manufacturer, produces EFP, gets more profit than CP, and motivates other manufacturers to produce EFP under renewable energy consumption. For online selling businesses, an advertising policy can increase profit rapidly. One can extend this paper by considering advertising policy for the online channel. In the internet world, everyone can get all the information about a product through the internet before purchasing. That's why the internet can rapidly boost the demand for the product in the market. The market demand was considered deterministic demand in this model; one can extend this model by considering stochastic demand under renewable energy consumption. The model can be developed with multi-echelon supply chain players (Padiyar et al. [41]).

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Abbreviations

The following abbreviations are used in this manuscript:

OAO	Online and offline
OOBOPS	Online-offline-BOPS
SCM	Supply chain model
PM	Production model
SSCM	Sustainable supply chain model
GEBM	Green energy business models
HRES	Hybrid renewable energy system
GDP	Green product development
CSR	Corporate social responsibility
CS	Corporate sustainability
SDG	Sustainable development goal
BOPS	Buy online and pick up in store
EFP	Eco-friendly product
CP	Conventional product
GQ	Green quality

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