Study and Analysis of Production Management using Renewable Energy for Sustainable Development

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Abstract

We can consider the energy efficiency through the study of modern supply chain management. The principal objective of this paper is to implement the use of green energy instead of regular energy in production process. We study how the use of green energy can be an alternative source of energy in large production sector. In our study there are two manufacturers and the problem is formulated using game theory. Here, two manufactures decide whether they produce green energy and use it for production or not. If they decide to produce, they need to design the production structure like production rate, production quantity, production cost and so forth. Our model shows that production of green energy is more cost effective and environmental friendly though the green production, which does not show the continuous increasing behavior of profitability. It may happen sometimes that the manufacturer produces less green energy and use it for overall production. As a result, to build the structure of the Model, careful steps are needed. The results of our research show that use of green energy is more ecofriendly and its market effect is positive.

Key words: *Green Production, Game Theory, Market Equilibrium.*

1.0 INTRODUCTION

Now-a days the most important problem we are facing is environmental pollution. Global pollution and improved awareness are prompting clients to look for better living choices. Green principles and strategy have become essentials for companies as public awareness of their environmental impact has increased. Today clients are actively supporting greener life style. So, Industrial sectors have been striving towards industrial reform. The rapid growth of green industries has provided benefits to the socio-economic development, reduced poverty, have created employment opportunities and thus increased quality of life [1]. At present the world is advancing towards a greener economy, businesses are embracing arrangements that may be useful to accomplish the objective. To achieve the sustainable future growth, we have to remove the constraints related to natural resources and environmental pollution. The competitiveness requires special attention for the long term sustainability because the competition is increasing within industry to industry both at national and international levels.. [2,3] defined the green industry as "A pathway of sustainable growth through green public investments and implementing government policy initiatives that encourage environmentally ecofriendly private investments". One of the popular strategy to halt environmental degradation is to build green industry. In our paper, we have introduced a new idea which emphasized the green production perspective. We consider two manufacturers, first manufacturer produces green energy and uses it to the production process. At the same time second manufacturer uses regular energy in production process. And for the case the vice versa is occurred. The competing manufacturers need to decide on their green energy production rate if they produce. And the quantities to produce goods and sell of their products given the cost of the raw materials. We find the optimal quantities for each of the green energy production scenarios and compare them to evaluate the value of green energy production for manufacturers and impact of it in different scenarios. We also examine, how the competition among manufacturers influence a manufacturer's decision to produce green energy and what is the impact of it in different scenarios on the manufacturer's decision and profit.

Finally, we inspected the ecological effect of production of green energy and demonstrated that the aggregate natural effect in the industry can be higher with the production of green energy if production cost (GE) is low. The article is organized as follows: section -1&2 describe introduction and literature review. Section 3,4&5 describe model analysis. Section 6&7 describe results and environmental impact and finally notations, parameters, decision variables and proofs of proposition are given in Appendix.

2.0 LITERATURE REVIEW

Reasonable advancement can be guaranteed through the asset compelled procedure of industries [4]. For this purpose, natural resources including water, minerals, fossil fuel and use of environmental resources should be reduced. Thus, use of environmentally sound products and reducing the consumption of resources help towards ensuring long run sustainability. Sreejith Balasubramnian,2014 investigated the understanding and green initiatives in the construction industries in UAE [5]. He proposed a structural analysis of the enablers of green supply chain management. He used an interpretive structural modelling (ISM) approach to identify the contextual relationship between enablers and to develop their structure. In their paper, Ali et al.,2012[6] established economic development activities which were postured with the help of green technology. Though the focus on green technology is not only sufficient component for sustainable development. To incur effective change and raising awareness proper education and training are also required. According to a report of Ugur Soytas and Ramazan Sari[7] the energy consumption policy has a negative impact on the economic growth but the use of renewable energy has significantly reduced the carbon emission of 31 development countries. Phillip Phan, Chester chamblers presented a critical approach of development in the field of industrial ecology [8]. Zhang et al focus on green design [9]. Robert. B Handfield studied a prescribed model on measures of green supply chain management with a focus on green product [10] Qing hua Zhu, Joseph Sarkis introduced closed loop supply chain (CLSC) for developing countries [11]. They examined the relationship between green supply chain management (GSCM) practice, environmental and economic performance. They used moderated regression analysis to evaluate the relationship between specific GSCM practice and performance. There is a complex relationship between the green economy and employment generation in both developed and developing countries [12,13]. Hasim et al developed an assessment tool named Green industrial performance scorecard (GIPS) to understand the performance of a green industry [14]. They showed that green practicing may reduce the harmful effects of the environment and it saves energy. Hoque and Clark showed that realizing the potential pollution prevention initiatives in Bangladesh reduced environmental degradation and in turn, saves cost [15]. The production of textile and fashion related products often requires high levels of energy and water consumption and emits a large quantities of pollutants to the environment. So environmental management has become an important responsibility for today's fashion and textile manufacturer [16]. In the study we see that adoption of green principles come up with certain advantages that not only benefit the world environmentally but economically and socially as well.

3.0 RESEARCH QUESTION

This research leads two important questions,

1. What is the impact of use of green energy instead of regular energy to the market?
2. What is the environmental impact of the use of green energy instead of regular energy for overall production?

3.1 Objective of the study:

1. To highlight the use of green energy for the production of the industry.
2. To optimize the cost and environmental effect using green energy for production of goods in an industry.
3. Compare the benefits of using green energy instead of regular energy for the manufacturers.

4.0 MODEL.

Here, we have considered a single-period model. The market comprises of two fabricates, manufacture 1 and manufacture 2, which pitch an indistinguishable item to the market. Both manufacture 1 and manufacture 2 contend in a heterogeneous market of size standardized to one, where clients are separated by their ability to - pay (apt), so that a client of sort φ has (apt) equivalent toφ for the item, where $\varphi \approx U[0,1]$ pursues the uniform likelihood dissemination. Therefore, if p indicates the market clearing value, at that point the net utility for the item inferred by a client of sort$[\varphi - p]$. Considering the likelihood of not buying, this utility means the average revenue function$p = 1 - q_1 - q_2$ where q_i is the amount created by manufacture i. A raw material is utilized in the production of the item offered by the two producers can be parched in the supply advertise as an expense of c_v per unit. To streamline documentation, we expect that the expensec_v incorporates both the expense of the raw material and any extra handling cost that the manufactures bring about to create the finished item. Here, we have considered two sources of energy. Sometimes the manufacturers produce green energy and use the production process, otherwise the regular energy is purchased from market and is used. The manufactures decide whether produce green energy or use regular energy by using game theory. There are three parts to the green energy production cost. Initially, if a manufacture produces green energy, it brings a fixed cost F to set the creation framework. Second, there is a green energy production cost for maker i, which is free of the volume of unit delivered. The manufactures are separated in their efficient of green energy production limit to such an extent that without loss of genericity $C_{g1} < C_{g2}$. Like the traditional cost, the production cost of green energy per unit also incorporates both the expense of production of green energy and any extra preparing cost that the manufactures acquire to deliver the completed items (using green energy). Ultimately, contingent upon the green energy production rate α_i picked by maker i, the producer causes an extra cost $\beta\alpha_i^2$, where $\beta<1$. The green energy production rate α_i is characterize to such an extent that the quantity of units produced by producer i is $\alpha_i q_i$.

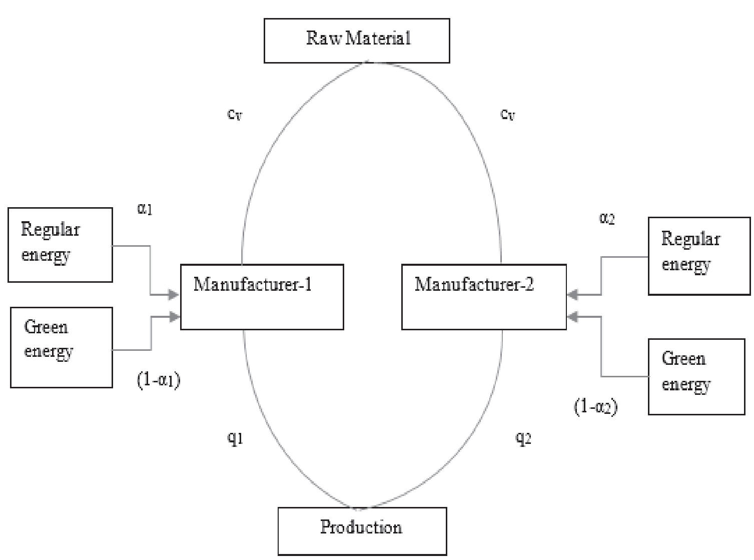

Fig. 1: The conceptual research model

Here, we think about four conceivable cases: (1) In case (G, G), the two manufactures deliver Green energy and in this manner, both settle on their general amount items to be sold to the market q_i and their individual creation rate α_i, i ϵ {1, 2}. (2) In case (G, R), manufacture1 produces Green energy and manufacture 2 does not. For this situation, both need to interpret on their general amount items to be sold to the market q_i, yet just manufacture 1 settles on its production rate α_1. (3) In case (R, G), manufacture 2 produces Green energy yet manufacture 1 does not. Correspondingly, to case 2, both provider need to settle on their general amount items to be sold to the market q_i, yet just maker 2 chooses its Green energy production rate α_2. (4) In case (R, R), neither manufacturers produce green energy and thus both decide only on their overall quantity to be sold to the market quantity q_i. The two manufacturers compete their production quantities q_i and their green energy production rate α_i, i ϵ {1,2}.

The profit for manufacturer i is therefore,

$$\prod_i(q_1, q_2) = q_i p(q_1, q_2) - (\alpha_i c_v c_{gi} + (1-\alpha_i) c_v c_R) q_i - \beta {\alpha_i}^2 - F.1\{\alpha_i > 0\} \quad (1)$$

The main term in (1) compares to income from offers of the items, where $P(q_{1,}q_2)$ is given above. The second term is the cost considering the weighted normal of production cost of green energy and cost of regular energy. The third term is a curved capacity of the green energy production rate. The last term is the settled expense of production of green energy and is equivalent to F if maker i delivers green energy and to 0 generally. There are no limit requirements for either manufactures. The arrangement of occasions is as per the following:

1. Each producer chooses whether to produce green energy, If produces so it brings a fixed cost F.
2. Each manufacture chooses its production amounts, given the market cost c_v.
3. Each producer settles on its green energy production rate $\alpha_i$in the event that it produces green energy.
4. Both manufactures have full data with respect to the green energy production cost structure of the two manufactures, and the harsh material expense. The market balance can be found by in reverse acceptance as pursues. First for each case, find each fabricator's particular green energy production rate (if proper all things considered) given the amounts q_1, q_2. At that point solve for that case. At that point each fabricator's best reaction whether produce green energy or not, given the other producer's activity whether produce green energy is gotten by contrasting the particular benefit. Here, we consider the crossing point of best reaction point and it is The Nast equilibrium. The determinations for all outcomes are given in the appendix.

Proposition 1: Impact of production of green energy to the market;

1) Manufacturer 1's amount $q_1^{GR} > q_1^{GG} > q_1^{RR} > q_1^{RG}$
2) Manufacturer 2's amount $q_2^{RG} > q_2^{GG} > q_2^{RR} > q_2^{GR}$
3) The market clearing cost $P^{GG} < P^{GR} < P^{RG} < P^{RR}$
4) Manufacturer 1's profit $\prod_1^{GR} > \prod_1^{GG}$and $\prod_1^{RR} > \prod_1^{RR}$
5) Manufacturer 2's profit $\prod_2^{RG} > \prod_2^{GG}$and $\prod_2^{RR} > \prod_2^{GR}$

(Source Equilibrium results in Appendix)

Proposition-1 expresses that the adjustments in the players choice under various production cases regarding the amounts by (1). We see that manufacturer 1 has the most elevated amount when it produces green energy, but the other producer does not and least when manufacturer 2 produces green erergy yet manufacturer 1 does not. This is comparative for manufacturer 2 at (2), with the exception of that manufacturer 2 has a higher amount in case (R, R) than in case (G, G) if its production capacity in respect to manufacturer 1 is low enough. Thus, production of green energy conveys a solid competetive favorable position to a producer, and the preferred standpoint is the most grounded when the other producer does not producing green energy. Concerning market clearing cost in (3) it is fascinating to take note of that it affirms that production of environmentally friendly energy is useful to the clients of two producers in the market as the cost under the production of green energy are lower than under the instance of not producing green energy. In this manner, while the two producers produce green energy (G, G) is the best case for clients as the market clearing cost is most minimal, in terms of market share every producer usually likes the uneven balance where it produces green energy however the competetor does not. The evaluating and amount favorable circumstances convert into benefit when a manufacterer produces green energy, it alludes that the competetor does not produce green energy. As portrayed over the present circumstance in the market is the equilibrium when one producer produces green energy and other does not.

5.0 RESULT ANALYSIS

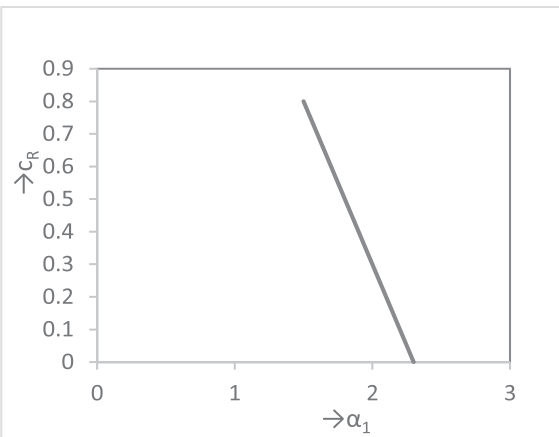

Fig. 2: Green energy production rate α_1 vs cost of a unit using regular energy c_R for manufacturer1

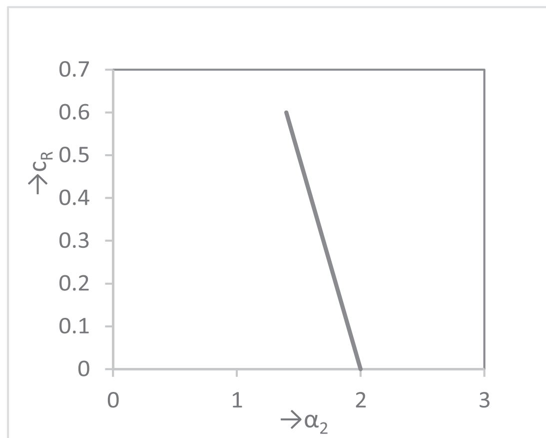

Fig. 3: Green energy production rate α_2 vs cost of a unit using regular energy c_R for manufacturer2

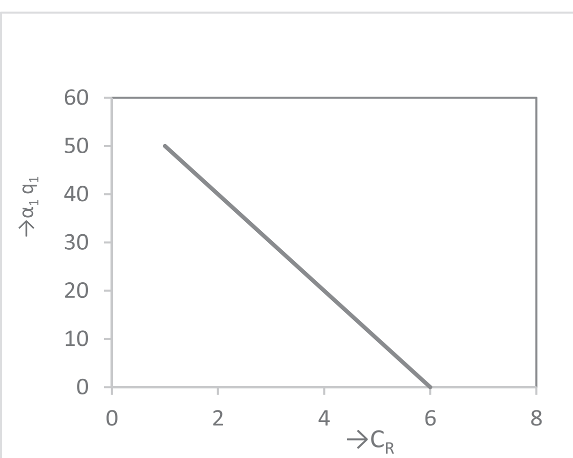

Fig. 4: production cost per unit using c_R vs amount of production of green energy for the manufacturer1

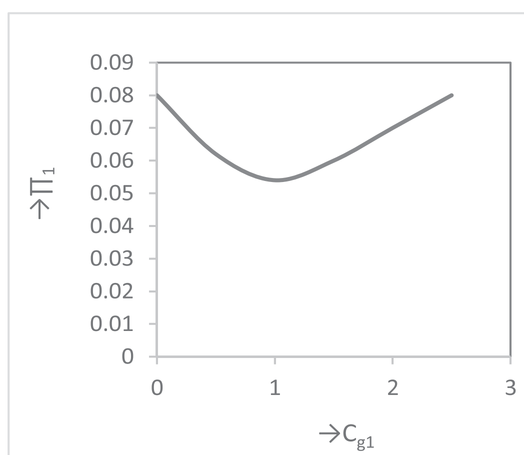

Fig. 5: production cost of green energy vs profit $\prod_1$ for manufacturer1

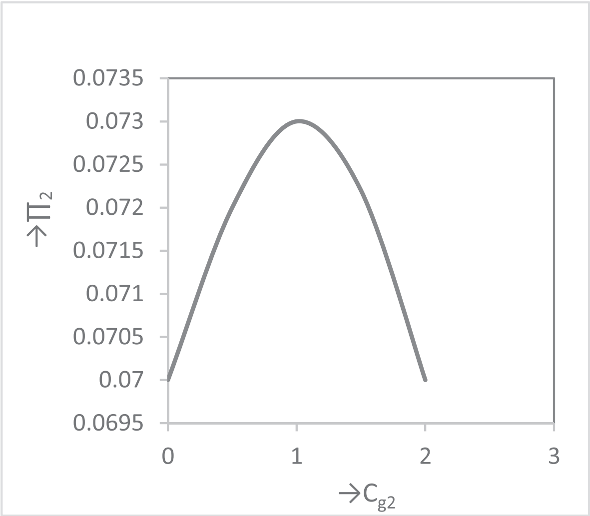

Fig. 6: production cost of green energy vs profit for manufacturer1

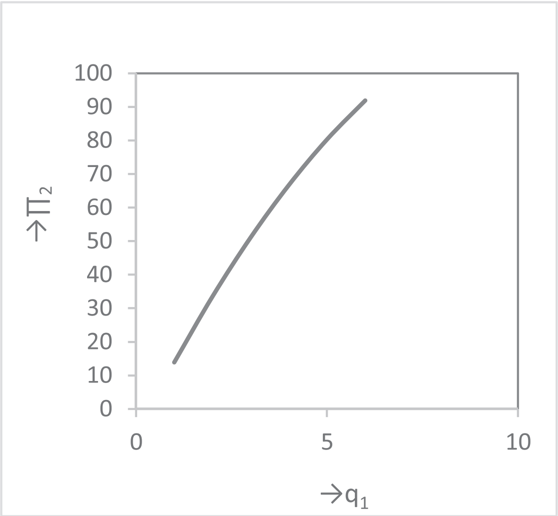

Fig. 7: Amount of production of green energy vs profit for manufacturer2

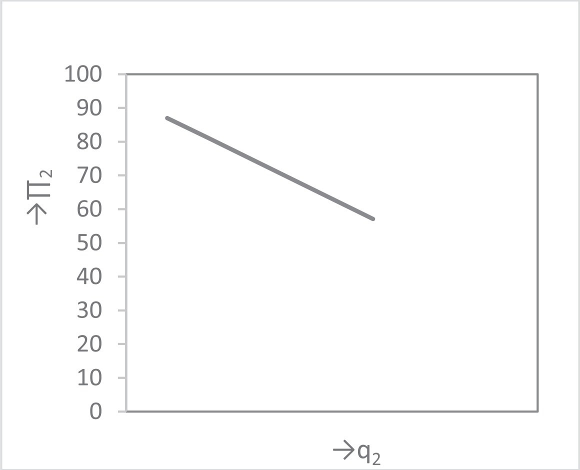

Fig. 8: Amount of production of green energy vs profit $\prod_2$ for manufacturer2

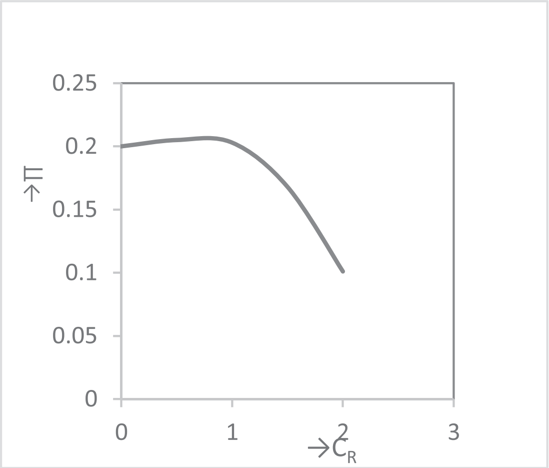

Fig. 9: Cost of regular energy c_R vs profit $\prod$ for the manufacturer

Here, we analyze the result of the case (G, G). Figures 2 and 3 state that when production rate of green energy is increasing the cost of a unite product using regular energy is decreasing. Figure 4 states that when the production cost per unit using regular energy is increasing, the amount of production of green energy is decreasing. But in above cases these should also increase because production of green energy is a cheaper alternative. It may not be true for high value of production cost of using regular energy and low value of cost parameter β. Figures 5 and 6 show the comparison of production cost and profit. The profit of Manufacturer-1 in figure 5 is decreasing up to a certain value of production cost of green energy and then increasing. In figure 6 the profit is increasing up to a certain level of production cost of green energy of manufacturer-2 and decreasing. Figure 7 illustrates, the amount of production of green energy is increasing, the profit is increasing. Figure 8 indicates the constant decreasing nature of profit function with the increasing value of amount of production of green energy. Figure 9 describes the concave nature of profit function comparing to the cost of per unite using regular energy.

6.0. ENVIRONMENTAL IMPACT

In this segment we utilized a Life Cycle Assessment (LCA) to decide the natural effect for the industry all in all. In a LCA approach, the ecological effect connect with one unit of the item can be estimated regarding energy consumption for instance. The item life cycle is contained raw materials, sourcing, creation, appropriation, use with client and end-of-life (EOL). Ecological effect per unit of an item created by regular energy as $\varphi_R = \varphi_{Re\,gularproduction} + \varphi_{use} + \varphi_{EOL}$. Here. $\varphi_{Re\,gularproduction}$ is the ecological effect per unit connect with the production stage with regular energy. φ_{use} is the natural effect per unit amid the utilization with the client and φ_{EOL} is the cost identified with EOL. At a similar way, the natural effect per unit of an item created by green energy can be composed by $\varphi_N = \varphi_{Greenproduction} + \varphi_{use} + \varphi_{EOL}$. Here, we signify both φ_{use} andφ_{EOL} are independent whether the item is produced by regular energy or by green energy, once the item leaves the maker's manufacturing plant, its utilization example and end-of-life fate don't rely upon its generation procedure as units made by using regular energy or green energy are identical. Thus, generation from regular energy and green energy affect just during production. Since, we are creating green energy both the producers in the amount of q_1 and q_2 unit individually. In this way, the natural effect for the industry for every one of cases kϵ {GG, GR, RG} is given by $\varphi^k = \varphi_R({q_1}^k + {q_2}^k) + \varphi_G({q_1}^k + {q_2}^k) + (\alpha_1 {q_1}^k + \alpha_2 {q_2}^k)$.where$p^k = 1 - Q^k$ and $Q^k = ({q_1}^k + {q_2}^k)$ and $Q^{GG} > Q^{GR} > Q^{RG} > Q^{RR}$. As a result, when comparing the industries' environmental impact for green energy production case k ϵ {GG, GR, RG} with no green energy production case {RR}, obviously any green energy production case will have a lower ecological effect than the no green energy production case. This is on account of for, k ϵ {GG, GR, RG} the expansion of initial two terms is constantly bigger than for {RR}, while the effect of last term is least or zero. In order to protect our environment, we introduced here green production management strategic formula. Recently China government enacted new environmental protection law to formulize the emissions discharge into a tax collected from industrial polluters. Relating to this phenomenon we have proposed a model with carbon tax policy. It is one of the three models for carbon emission in GSCM.

7.0. CONCLUSION

In this paper we study the impact of production of green energy and use of it instead of regular energy in the production process. The competing manufacturers decide on their green energy production rate (if they produce green energy). We consider four production scenarios among two manufacturers. If first manufacturer produces green energy, then second manufacturer uses regular energy and the case vice-versa occurs. To determine when and which manufacturer produces green energy we use game theory model as two players play the game in four different cases like GG, GR, RG and RR. We find out optimal quantities for each of the production cases and compare them to evaluate the value of green energy production and impact of it in the market as well as the environment. We show that product of green energy can indeed be a competitive advantage to the manufacturers and the advantage is the strongest when the other manufacturer does not produce green energy. In the further research the amount of production of green energy can be optimized. Finally, we examined the environmental impact of green energy production. Here, we also introduced a Carbon tax model to discourage the manufacturer to emission more greenhouse gases.

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APPENDIX:

Proof of proposition 1;

Case (GG): $\prod_i(q_1, q_2) = q_i p(q_1, q_2) - (\alpha_i c_v c_{gi} + (1-\alpha_i) c_v c_R) q_i - \beta \alpha_i^2 - F.1\{\alpha_i > 0\}$

$$\Rightarrow \prod_i = q_i(1 - q_1 - q_2 - \alpha_i c_v c_{gi} - c_v c_R + \alpha_i c_v c_R) - \beta \alpha_i^2 - F$$

$$\Rightarrow \prod_i = q_i(1 - q_1 - q_2 + \alpha_i(c_v c_R - c_v c_{gi}) - c_v c_R) - \beta \alpha_i^2 - F$$

$$\Rightarrow \prod_1 = q_1(1 - q_1 - q_2 + \alpha_1(c_v c_R - c_v c_{g1}) - c_v c_R) - \beta \alpha_1^2 - F$$

$\therefore \prod_1 = q_1(1 - q_1 - q_2 + \alpha_1 \Delta - c_v c_R) - \beta \alpha_1^2 - F$, $\quad \because c_v c_R - c_v c_{g1} = \Delta$

$\because \frac{\partial \prod_1}{\partial \alpha_1} = 0, \alpha_1 = \frac{q_1 \Delta}{2\beta} \Rightarrow \alpha_1 = \frac{(c_v c_R - c_v c_{g1})}{2\beta} q_1$

Again, $\prod_2 = q_2(1 - q_1 - q_2 + \alpha_2(c_v c_R - c_v c_{g2}) - c_v c_R) - \beta \alpha_2^2 - F$

$\therefore \prod_2 = q_2(1 - q_1 - q_2 + \alpha_2 \gamma \Delta - c_v c_R) - \beta \alpha_2^2 - F \because c_v c_R - c_v c_{g2} = \gamma \Delta$

$\because \frac{\partial \prod_2}{\partial \alpha_2} = 0, \quad \alpha_2 = \frac{q_2 \gamma \Delta}{2\beta} \Rightarrow \alpha_2 = \frac{(c_v c_R - c_v c_{g2})}{2\beta} q_2$

Again, $\frac{\partial \prod_1}{\partial q_1} = 0,$

$\therefore q_1 = \frac{2\beta(1 - c_v c_R) - (2\beta - \gamma^2 \Delta^2)}{12\beta^2 - 4\beta(1+\gamma^2)\Delta^2 + \gamma^2 \Delta^4}$

$$\Rightarrow q_1 = \frac{2\beta(1 - c_v c_R) - (2\beta - \gamma^2 \Delta^2)}{12\beta^2 - 4\beta(c_v c_R - c_v c_{g1})^2 - 4\beta(c_v c_R - c_v c_{g2})^2 + (c_v c_R - c_v c_{g1})^2 (c_v c_R - c_v c_{g2})^2}$$

And, $\frac{\partial \prod_2}{\partial q_2} = 0, \therefore q_2 = \frac{2\beta(1 - c_v c_R) - (2\beta - \Delta^2)}{12\beta^2 - 4\beta(1+\gamma^2)\Delta^2 + \gamma^2 \Delta^2}$

$\Rightarrow q_2 = \frac{2\beta(1 - c_v c_R) - (2\beta - (c_v c_R - c_v c_{g1})^2)}{12\beta^2 - 4\beta(c_v c_R - c_v c_{g1})^2 - 4\beta(c_v c_R - c_v c_{g2})^2 + (c_v c_R - c_v c_{g2})^2}$

Substituting q_1 and q_2 in profit function,

$\prod_1^{GG} = \frac{\beta(1 - c_v c_R)^2 - (4\beta - \Delta^2)(2\beta - \gamma^2 \Delta^2)}{(12\beta^2 - 4\beta(1+\gamma^2)\Delta^2 + \gamma^2 \Delta^4)^2} - F \quad \Rightarrow \prod_1^{GG} =$
$\frac{\beta(1 - c_v c_R)^2 - (4\beta - (c_v c_R - c_v c_{g1})^2)(2\beta - (c_v c_R - c_v c_{g2})^2)}{(12\beta^2 - 4\beta(c_v c_R - c_v c_{g1})^2 - 4\beta(c_v c_R - c_v c_{g2})^2 + (c_v c_R - c_v c_{g1})^2 (c_v c_R - c_v c_{g2})^2)^2} - F$ And, $\prod_2^{GG} =$

$\frac{\beta(1-c_v c_R)^2-(4\beta-\gamma^2\Delta^2)(2\beta-\Delta^2)^2}{(12\beta^2-4\beta(1+\gamma^2)\Delta^2+\gamma^2\Delta^4)^2} - F \Rightarrow \prod_1{}^{GG} = \frac{\beta(1-c_v c_R)^2-(4\beta-(c_v c_R-c_v c_{g2})^2)(2\beta-(c_v c_R-c_v c_{g1})^2)}{(12\beta^2-4\beta(c_v c_R-c_v c_{g1})^2-4\beta(c_v c_R-c_v c_{g2})^2+(c_v c_R-c_v c_{g1})^2(c_v c_R-c_v c_{g2})^2)^2} - F$

Case (GR):

$$\Rightarrow \prod_i = q_i(1-q_1-q_2+\alpha_i(c_v c_R - c_v c_{gi}) - c_v c_R) - \beta\alpha_i{}^2 - F$$

$$\Rightarrow \prod_1 = q_1(1-q_1-q_2+\alpha_1(c_v c_R - c_v c_{g1}) - c_v c_R) - \beta\alpha_1{}^2 - F$$

$\therefore \prod_1 = q_1(1-q_1-q_2+\alpha_1\Delta - c_v c_R) - \beta\alpha_1{}^2 - F$, $\quad \because c_v c_R - c_v c_{g1} = \Delta$

$\because \frac{\partial \prod_1}{\partial \alpha_1} = 0, \alpha_1 = \frac{q_1\Delta}{2\beta} \Rightarrow \alpha_1 = \frac{(c_v c_R - c_v c_{g1})}{2\beta} q_1$

α_2 is not occurring because manufacturer does not produce green energy.

Again, $\frac{\partial \prod_1}{\partial q_1} = 0, \quad q_1 = \frac{\beta(1-c_v c_R)}{3\beta-\Delta^2} \Rightarrow q_1 = \frac{\beta(1-c_v c_R)}{3\beta-(c_v c_R-c_v c_{g1})}$

And, $\frac{\partial \prod_2}{\partial q_2} = 0, \Rightarrow q_2 = \frac{(1-c_v c_R)(2\beta-\gamma^2\Delta^2)}{2(3\beta-\Delta^2)}$

$\Rightarrow q_2 = \frac{(1-c_v c_R)(2\beta-(c_v c_R-c_v c_{g2})^2)}{2(3\beta-(c_v c_R-c_v c_{g1})^2)}$

Putting q_1 and q_2 in the profit function,

$$\prod_1{}^{GR} = \frac{\beta(1-c_v c_R)^2-(4\beta-\Delta^2)}{4(3\beta-\Delta^2+\gamma^2\Delta^4)^2} - F$$

$\Rightarrow \prod_1{}^{GR} = \frac{\beta(1-c_v c_R)^2-(4\beta-(c_v c_R-c_v c_{g1})^2)}{4(3\beta-(c_v c_R-c_v c_{g1})^2+(c_v c_R-c_v c_{g1})^2(c_v c_R-c_v c_{g2})^2)^2} - F$

And, $\prod_2{}^{GR} = \frac{(1-c_v c_R)^2(2\beta-\Delta^2)^2}{4(3\beta-\Delta^2)^2} - F$

$\Rightarrow \prod_2{}^{GR} = \frac{(1-c_v c_R)^2-(2\beta-(c_v c_R-c_v c_{g1})^2)^2}{4(3\beta-(c_v c_R-c_v c_{g1})^2)^2} - F$

Case (RG): This case is vice-versa of case (GR)
α_1 is not occurring because manufacturer does not produce green energy.

$\because \frac{\partial \prod_2}{\partial \alpha_2} = 0, \alpha_2 = \frac{q_1\Delta}{2\beta} \Rightarrow \alpha_2 = \frac{(c_v c_R - c_v c_{g1})}{2\beta} q_2$

And, $q_1 = \frac{(1-c_v c_R)(2\beta-\gamma^2\Delta^2)}{2(3\beta-\Delta^2)}$ $\Rightarrow$ $q_1 = \frac{(1-c_v c_R)(2\beta-(c_v c_R - c_v c_{g2})^2)}{2(3\beta-(c_v c_R - c_v c_{g1})^2)}$

$q_2 = \frac{\beta(1-c_v c_R)}{3\beta-\Delta^2} \Rightarrow q_2 = \frac{\beta(1-c_v c_R)}{3\beta-(c_v c_R - c_v c_{g1})}$

Again, $\prod_1{}^{RG} = \frac{(1-c_v c_R)^2(2\beta-\Delta^2)^2}{4(3\beta-\Delta^2)^2} - F$

$\Rightarrow \prod_1{}^{RG} = \frac{(1-c_v c_R)^2-(2\beta-(c_v c_R - c_v c_{g1})^2)^2}{4(3\beta-(c_v c_R - c_v c_{g1})^2)^2} - F$

And, $\prod_2{}^{RG} = \frac{\beta(1-c_v c_R)^2-(4\beta-\Delta^2)}{4(3\beta-\Delta^2+\gamma^2\Delta^4)^2} - F$

$\Rightarrow \prod_2{}^{RG} = \frac{\beta(1-c_v c_R)^2-(4\beta-(c_v c_R - c_v c_{g1})^2)}{4(3\beta-(c_v c_R - c_v c_{g1})^2+(c_v c_R - c_v c_{g1})^2(c_v c_R - c_v c_{g2})^2)^2} - F$

Case (RR): In this case both manufacturer do not produce green energy, so α_1 and α_2 are not occurring.

From $\frac{\partial \prod_1}{\partial q_1} = 0,\ and\ \frac{\partial \prod_2}{\partial q_2} = 0$, we have,

$q_1 = \frac{(1-c_v c_R)}{3}, q_2 = \frac{(1-c_v c_R)}{3}$, Putting q_1 and q_2 in the profit function,

$\prod_1{}^{RR} = \frac{(1-c_v c_R)^2}{9}$ And, $\prod_2{}^{RR} = \frac{(1-c_v c_R)^2}{9}$.