Study of sustainability of a paper recycling supply chain based on profit optimization

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Abstract

In the last few decades, recycling and closed loop supply chain became very important research topics due to their economic and environmental impacts. Paper recycling is one of the most important industries as it saves natural resources as trees , saves production energy and landfill space.

A multi echelon, multi-product, single facility capacitated closed loop supply chain model is proposed in this paper. A linear programming model is presented to optimize profit in a capacitated paper manufacturing supply chain producing different paper grades. Further, in this paper the environmental and social impacts are studied based on profit optimization at different production capacities and different waste costs.

Key words: closed loop supply chain- green supply chain-paper industry-optimization-linear programming –reverse supply chain-recycling –sustainable supply chain

1. Introduction

Recycling is defined in the WFD as "any recovery operation, by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes" [1]. Today, closed-loop supply chain management is defined as the design, control, and operation of a system to maximize value creation over the entire life cycle of a product with dynamic recovery of value from different types and volumes of returns over time [2].

In the last few decades, recycling and closed loop supply chain became very important due to their economic and environmental benefits. Among the most important types of recycling is paper recycling due to the following [3]:

i. Protecting the environment natural resources through reducing number of trees cut. One ton of recycled fiber is equivalent to the pulp of 17 trees.
ii. Less energy consumed in production of recycled paper compared to virgin pulp.
iii. Saving landfill space, every ton of recycled fiber saves approximately 3 yd3 of land.

R.K.Pati et.al. [4] Proposed an economic analysis of paper recycling in comparison to wood as a raw material in paper industry through a linear optimization model for cost minimization. In this paper, an environmental cost was added to the cost minimization objective which reflects the authors' ecological interest. This research discussed shortage analysis, sensitivity analysis and trend analysis for the supply chain. It was concluded from the shortage analysis that for a degree of 80% or less shortage in supply chain, recycling is more economical than virgin pulp. As a result, this encourages the manufacturers to use waste paper as a raw material.

Sensitivity analysis was performed to guide the supply chain managers to find a way to increase waste paper recovery such as giving incentives to vendor- customer and establishing a high standard collection system, this technique was found to reduce the total supply chain cost.
Finally, the authors discussed the results of the trend analysis of waste paper recovery to show the importance of finding strategies to collect minimum quality of waste paper to reach the economic benefits of recycling. As a conclusion, it was found that recycling was better than virgin pulp as a raw material economically and environmentally as it decreases no. of trees cut (natural resources) and utilize waste paper as a solid waste.

Environmental impact of paper recycling was further studied by **JM Bloemhof et.al. [5]** Who presented a linear optimization model to minimize the environmental impact of paper recycling and the factors affecting it? The paper stated that relocation has strong effect on the environmental impact. It was shown that as recycling takes place in areas with large supply of waste paper, environmental impact improves by 4-8%.In addition, the paper shows that policies of regulated levels of recycled paper is not efficient and it is better to adapt flexible policies, giving an example that areas producing large quantities of graphic paper should focus on virgin pulp production.

Life cycle assessments of waste paper was further investigated by **A. Villanueva [6]** Comparing between the effect of recycling, incineration and landfill. A total of 9 LCA studies containing 73 scenarios collected from international literature review showed the benefits of recycling over landfill and incineration .This conclusion was found despite different locations.
J.Laurijssen et.al. [7] Studied the impact of paper recycling on energy and CO2 emissions. The paper compares the effect of different paper grades on CO2 emissions and energy intensity .The study compared between 2 cases when there are no constraints on resources available and when constraints on biomass are applied. It was found that in the second case recycled paper has the lowest energy intensity and the lowest CO2 foot print. It was concluded that life cycle energy decreases with increasing the rates of recycling.

A multi-product, multi-time, multi-echelon capacitated closed loop supply chain model in uncertain environment was proposed by **A.Jindal [8] .**In this model a fuzzy MILP model was used to reach a balance between the feasibility degree and degree of satisfaction .The effectiveness of the proposed solution applied was investigated through an example. Finally, the authors mentioned that the model can be used in various industries but for large sized business problems efficient heuristics need to be developed.

Information have a significant importance in supply chain. **Michael Ketzenberg [9]** explored in his paper the value of information in a capacitated closed loop supply chain .It was found that there wasn't one type of information dominant. For example, Yield information is the most valuable with high rates of returns, high yield loss, and high capacity availability. While capacity information is also most valuable with high rates of return and high return variability, high penalty costs and, Demand information is most valuable with high demand variability, high capacity availability and a high unit holding cost rate. It was found that the capacity information demonstrated the largest value in 55% of the experiments studied.

In this paper, a closed loop supply chain for paper industry is introduced. This model main objective is to study the environmental and social benefits based on economical (profit) optimization

2. Proposed supply chain framework

In the shown figure (1), a multi-echelon, multi-product, single-facility closed loop supply chain for paper industry framework is introduced. The model consists of a production facility producing 3 different products, sorting area and waste paper market area. The main objective of the model is to study the supply chain sustainability in the form of environmental impact indicators (eco indicator 95) [10] and the social impact presented as number of job opportunities.

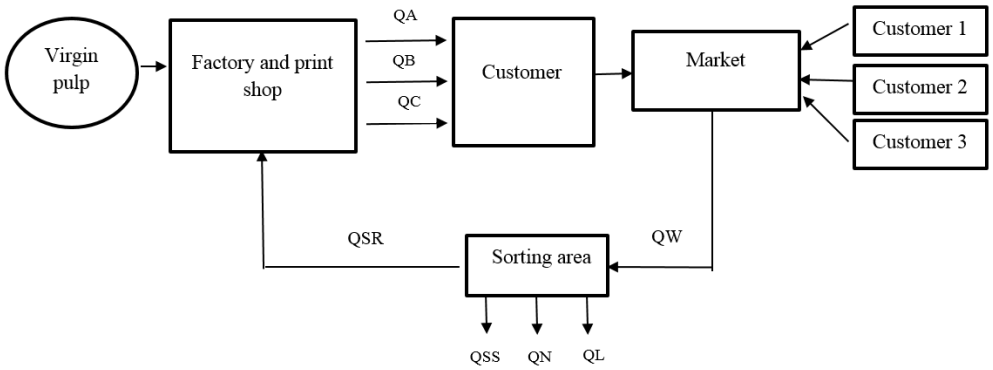

Figure 1: closed loop supply chain network for paper industry

2.1. Model assumptions

1) The production facility is capacitated.
2) Three types of paper products are produced. [11]
   Type A: made of 100% virgin pulp
   Type B: made of 50% virgin pulp and 50% recycled fibers
   Type C: made of 100% recycled fibers
3) 20% of waste paper quantity bought is to be incinerated or landfilled.
4) 10% of produced quantities at the production facility is to be returned back as dash after treatment in a nearby facility.
5) Each 125 tons of unsorted waste paper offers a job opportunity. [12]

2.2. Nomenclature

CapF	Capacity of production in factory
CapS	Capacity of production in sorting area
CW	Cost of buying unsorted waste paper from the market/ton
CS	Cost of preparation and sorting of waste paper at sorting area/ton
DEMA	Customer Demand of paper quality A
DEMB	Customer Demand of paper quality B
DEMC	Customer Demand of paper quality C
EL	Environmental impact of waste paper landfilling
EN	Environmental impact of waste paper incineration
EPA	Environmental impact of production of paper grade (A)
EPB	Environmental impact of production of paper grade (B)
EPC	Environmental impact of production of paper grade (C)
ER	Environmental impact of paper recycling
ET	Environmental impact of paper transportation
LC	Paper Landfill cost/ton
NC	Paper incineration cost/ton
PA	Cost of virgin pulp and production of paper grade (A)/ton
PB	Cost of virgin pulp and production of paper grade (B)/ton
PC	Cost of production of paper grade (C)/ton
PPS	Percentage of sorted waste paper
RA	Selling price of paper grade (A) /ton
RB	Selling price of paper grade (B) /ton
RC	Selling price of paper grade (C) /ton
RS	Selling price of sorted waste paper/ton
TC	Paper transportation cost/ton kilometer

VS	Variable number of jobs at sorting area
XFC	Distance from factory to customer in km
XMS	Distance from Market to sorting area in km
XSF	Distance from sorting area to factory

2.3. Decision Variables (All quantities in tons)

QA: quantity of paper grade (A) produced in factory and transported to customer
QB: quantity of paper grade (B) produced in factory and transported to customer.
QC: quantity of paper grade (C) produced in factory and transported to customer.
QL: quantity of landfilled waste paper at sorting area.
QN: quantity of incinerated waste paper at sorting area
QW: quantity of unsorted waste paper bought from the Market to sorting area.
QSR: quantity of sorted wastepaper sent to factory to be recycled
QSS: quantity of sorted wastepaper sent to factory to be sold.

2.4. Objective

The objective of this paper is to maximize the profit of the proposed loop supply chain through optimization of quantities through the supply chain .Further, the environmental impact and the number of job opportunities is calculated at each profit value to study the sustainability of the supply chain.

A) Maximizing profit:

Profit=Revenue from selling different grades of paper products +Revenue from selling sorted waste paper at sorting area-Cost of production of different paper grades-Cost of Transportation-Cost of incineration and landfill-Cost of buying waste paper from market-Cost of preparation and sorting at sorting area

Z1= (RA*QA+RB*QB+RC*QC) + (RS*QSS)-(PA*QA+PB*QB+PC*QC)-[(TC*XFC*∑Q(A+B+C)) -(TC*XMS*QW)-(TC*XSF*QSR)]-[(LC*QL)-(NC*QN)]-[(CW*QW)-(CS*QW)]

Subject to:

Sorting area balance
0.1∑Qa-c+QW-QL-QN-QSS-QSR=0

Balance ratio of recycled paper in different paper products
QSR-0.5QB-QC=0

Production capacity constraint
∑QA-C=<CapF

Sorting capacity constraint
QW=<CapS

Different grades of Paper demand constraint
QA<=DEMA
QB<=DEMB
QC<=DEMC

Landfill and incineration quantities constraint
QL+QN>=0.2*QW

B) environmental impact calculated

Environmental impact=Environmental impact of production of different paper grades+ Environmental impact of incineration+ Environmental impact of landfill+ Environmental impact of transportation+ Environmental impact of recycling

Z2=(EPA*QA+EPB*QB+EPC*QC)+EN*QN+EL*QL+ET*XFC*∑Q(A+B+C)+ET*XSF*QSR+ET*XMS*QW-ER*QSR

C) job opportunities calculated

Number of job opportunities=number of variable jobs in sorting area per ton*quantity of unsorted waste paper in tons

Z3= (VS*QW)

The mathematical model was solved using Microsoft excel solver software on a computer with 2.50 GHz Inteli5 processor and RAM 6.0 GB 64-bit.

3. Results and discussion.

In the introduced model, profit optimization was tested through different production facility capacities and different waste paper costs. Followed by a study of the impact of the produced on environmental and social aspects.
The model proposed experiments at 4 factory capacities which are (10000,50000, 100000 and 150000) and each capacity in tested at different waste paper cost presented as a percentage of virgin pulp cost which are (0%,5%,8%10%,15% and 20%).

3.1. Study for the effect of waste cost on optimal profit for different production capacities

Variables: production facility capacity- profit –waste cost

Assumptions: Demand of the three types of paper products produced is equal to:
Type A: 50000 tons - Type B: 50000 tons -Type C: 50000 tons

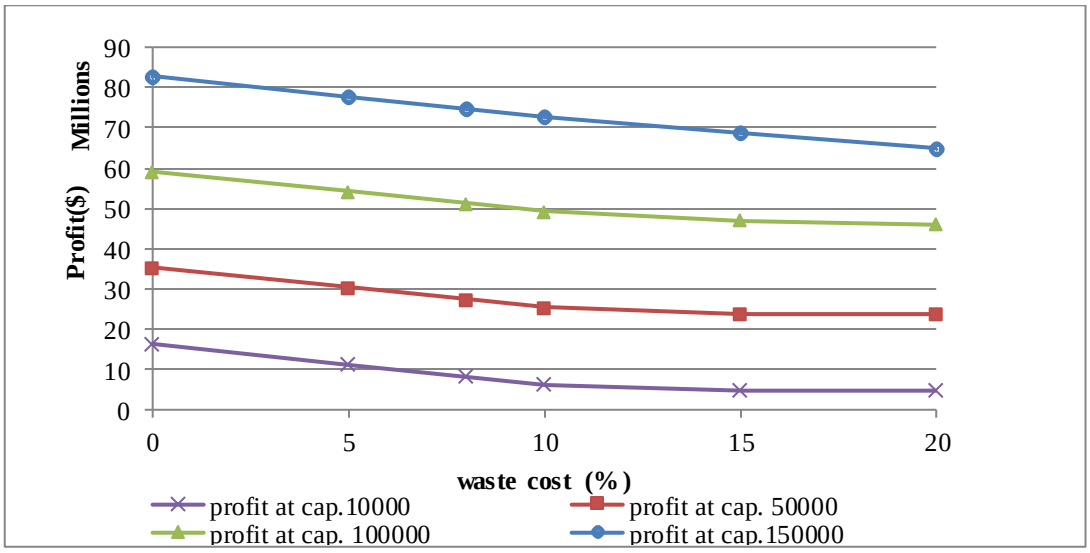

Figure 2: The effect of waste cost as a percentage of virgin pulp cost on the profit at different production capacities

Observation: As shown in fig. [2], as the waste cost increase, the profit decreases. This behavior is obvious along all capacities. The highest profit values occurs at capacity (150000 tons) and the lowest profit values occurs at capacity (10000 tons).

As mentioned above, the profit in all capacities decrease as the waste cost increases but the percentage of decline is not the same through all costs and capacities. Fig. [3] Showed that the percentage of decrease in profit was steep through the costs (0%-8%-10%).On the other hand, higher costs (15%-20%) showed a negligible percentage of decrease in profit compared to the lower costs.

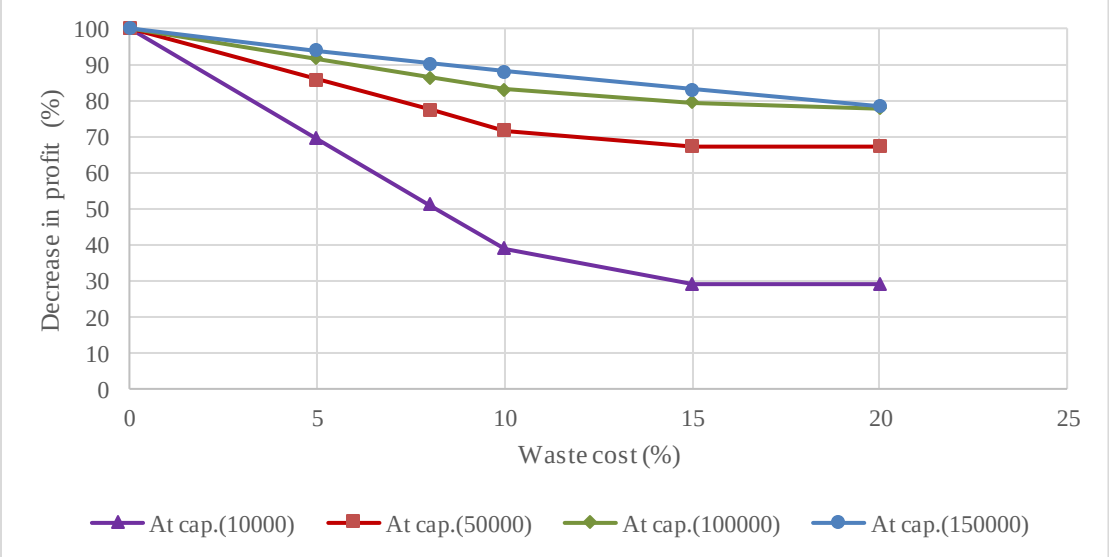

Figure 3: The effect of waste costs on the percentage decrease in profit for different production capacities

Discussion

Studying the behavior of the previous curves, it appears that the change in waste cost affects the quantities of waste paper to be bought (QW) and hence the quantities of waste paper to be recycled (QSR) and its products (QB-QC)

As the waste cost increase, the profit decreases as the main raw material for paper grade C is becoming more expensive causing a steep decrease till waste cost (10%).Starting from waste cost (15%), the drop in profit values becomes negligible except for capacity (10000 tons) as the optimization results shows no more production of paper grade C, so the effect of waste paper cost is nearly neglected.

3.2. Studying the sustainability of the supply chain, it was found that:

3.2.1. Calculated Environmental impact of the supply chain

Variables: production facility capacity- environmental impact –waste paper cost

Observation: It is shown in fig. [4], the environmental impact has low and constant values through waste costs (0% to 10%), starting from waste cost (15%) a huge rise in the values of the environmental impact appears.
This attitude was true for all capacities except for capacity (150000 tons) as it was nearly constant along all waste costs due to higher production capacity and fulfilling all demands of the three paper grades along all paper costs.

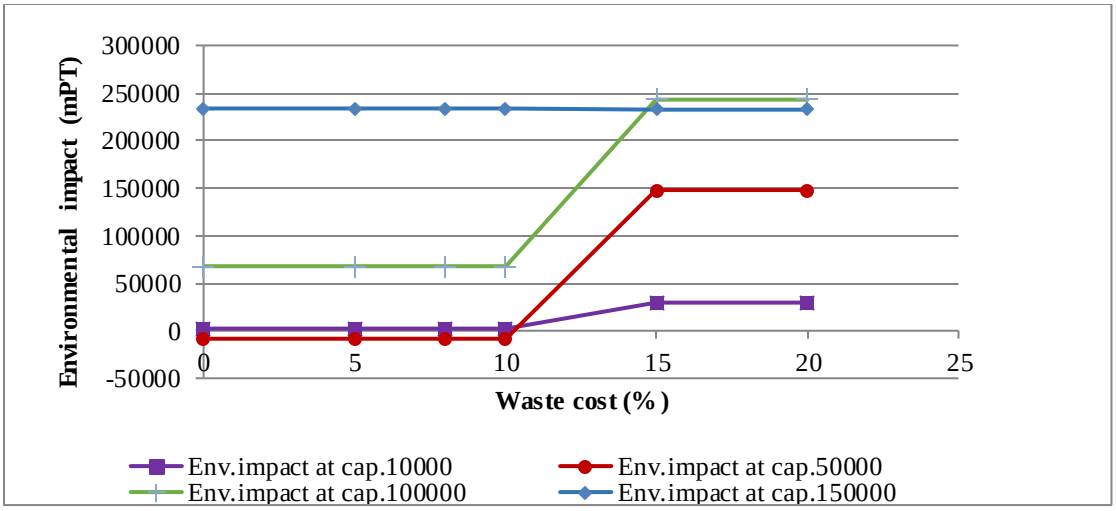

Figure 4: The effect of waste cost as a percentage of virgin pulp cost on Environmental impact at different production capacities

Discussion

As mentioned above, starting from waste cost (15%) no more grade C paper is produced and no waste paper is bought to be recycled. The effect of putting off recycling is clear in fig.[4] showing a huge rise in environmental impact values and affecting the environment in a negative way.

3.2.2. Calculated Job opportunities for the supply chain

Variables: production facility capacity- job opportunities –waste paper cost

Observation: Fig. [5] Shows that all capacities started with 800 job opportunities and remained constant till waste cost (10%).At waste cost 15% and 20%, the number of job opportunities started to show a steep decline in its values.

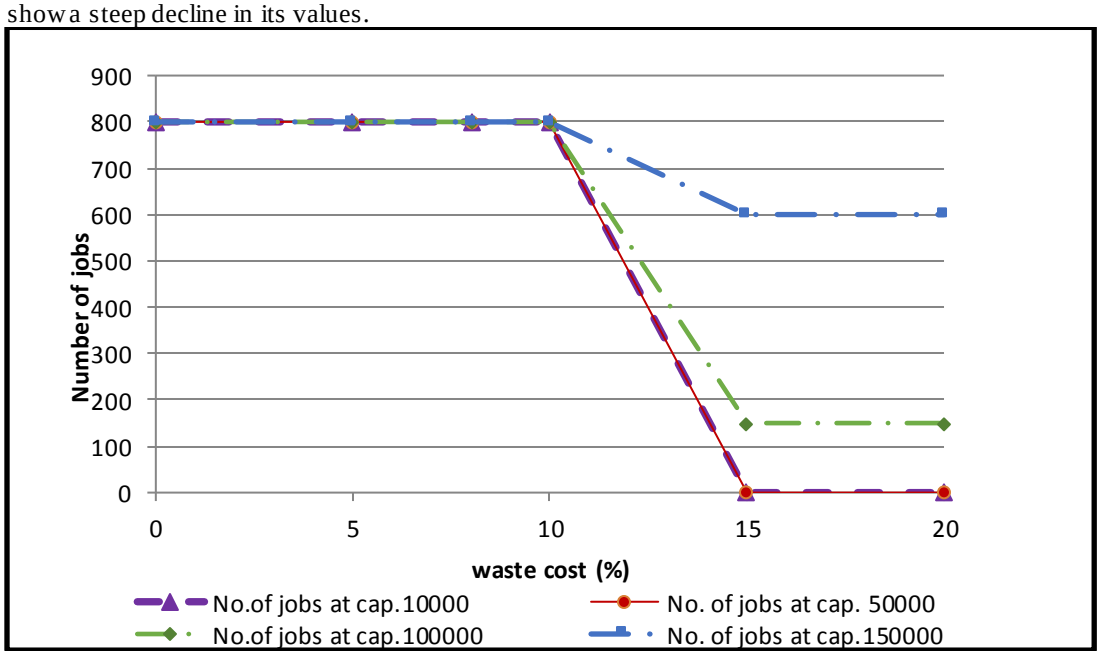

Figure 5: The effect of waste cost as a percentage of virgin pulp cost on number of job opportunities at different production capacities

Discussion:

It is shown that the behavior of job opportunities curves [5] is opposite to that of the previously discussed environmental impact curves [4].

As the waste cost increases, the quantity of waste paper to be bought (QW) decreases and hence the job opportunities decreases.
At waste costs 15% and 20%, capacities 10000 and 50000 showed zero job opportunities as no waste paper is bought. At capacities 100000 and 150000 the situation is slightly better as the job opportunities decreased to 150 and 600 respectively.

Conclusion

It was clear that the optimal profit decreases rapidly with the increase of the waste paper cost as long as paper grade C is produced and waste paper is to be bought. This decrease starts to show a nearly constant behavior when grade C production stops.

For the environmental impact, the study show that recycling is very beneficial for the environment. As the waste cost increases and quantities of recycled paper decreases causing a huge rise in the environmental impact and affecting the environment in a negative way.
Unlike the environmental impact, the number of job opportunities decreases as the waste cost increases affecting the social life.
Finally, from the previous study, it was shown that the recycling has a great effect on profit, environmental impact and number of job opportunities of the supply chain.

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Biography

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