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นางสาวกิตติพร นิเทศวิทยานุกูล

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STUDY ON ECONOMIC AND ENVIRONMENT EFFICIENCY OF OFFSET AND DIGITAL PRINTING SYSTEMS

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A Thesis Submitted in Partial Fulfillment of the Requirements
For the Degree of Master of Engineering Program in Chemical Engineering
Department of Chemical Engineering
Faculty of Engineering
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โรงพิมพ์เป็นอุตสาหกรรมขนาดเล็ก ซึ่งมักตั้งกระจายตัวอยู่ในชุมชนทั่วไป การประเมินผลกระทบต่อสิ่งแวดล้อมจึงมีความสำคัญ เพราะของเสียจากโรงพิมพ์จะส่งผลกระทบโดยตรงต่อชุมชน งานวิจัยนี้ทำการประเมินผลกระทบต่อสิ่งแวดล้อม และต้นทุนในการพิมพ์โดยเปรียบเทียบระหว่างระบบการพิมพ์ที่นิยมใช้กันมากที่สุดในอุตสาหกรรมการพิมพ์ในประเทศไทยคือระบบการพิมพ์ออฟเซต และระบบการพิมพ์ทางเลือกใหม่คือระบบการพิมพ์ดิจิตอล โดยพิจารณา 4 กรณีศึกษาด้วยกัน งานพิมพ์สีดำ 1 หน้าพิมพ์ 70% ของหน้ากระดาษ งานพิมพ์ 4 สีพิมพ์ 100 % ของหน้ากระดาษ งานพิมพ์หนังสือ 1 สี 76 หน้า และงานพิมพ์หนังสือ 4 สี 132 หน้า ผลจากการประเมินผลกระทบต่อสิ่งแวดล้อมโดยใช้ Eco-indicator 99 พบว่า ผลกระทบต่อสิ่งแวดล้อมจากระบบการพิมพ์ออฟเซตส่วนใหญ่เกิดขึ้นจากขั้นตอนการสร้างเพลท เมื่อเฉลี่ยผลกระทบต่อสิ่งแวดล้อมต่อ 1 ชิ้นงานพบว่าผลกระทบต่อสิ่งแวดล้อมจะแปรผกผันกับปริมาณการพิมพ์ที่มากขึ้น จากนั้นได้มีการศึกษาผลกระทบต่อสิ่งแวดล้อมกรณีเปลี่ยนสารประกอบในหมึกพิมพ์ออฟเซตจากเบนซีน เป็นน้ำมันพืช พบว่าผลกระทบต่อสิ่งแวดล้อมจากระบบการพิมพ์ออฟเซตลดลงในด้านสารก่อมะเร็ง ผลกระทบจากสารอินทรีย์ต่อระบบทางเดินหายใจ และพิษต่อระบบนิเวศน์ แต่ส่งผลในทิศทางตรงข้ามในด้านการใช้ทรัพยากรที่ดิน การศึกษาเปรียบเทียบผลกระทบต่อสิ่งแวดล้อมระหว่างระบบการพิมพ์ออฟเซตและระบบการพิมพ์ดิจิตอล พบว่าระบบการพิมพ์ออฟเซตส่งผลกระทบต่อสิ่งแวดล้อมสูงกว่าระบบการพิมพ์ดิจิตอลในทุกด้าน ระบบการพิมพ์ดิจิตอลจึงเป็นทางเลือกหนึ่งในการลดปริมาณผลกระทบต่อสิ่งแวดล้อม การศึกษาต้นทุนในการพิมพ์พบว่าการพิมพ์ปริมาณน้อยระบบการพิมพ์ดิจิตอลจะมีต้นทุนต่ำกว่าระบบการพิมพ์ออฟเซต แต่ถ้าพิมพ์ปริมาณมากระบบการพิมพ์ออฟเซตจะมีต้นทุนถูกกว่าและต้นทุนจะลดลงตามปริมาณการพิมพ์ที่มากขึ้น

ภาควิชา ....วิศวกรรมเคมี............ลายมือชื่อนิสิต......กิตติพร นิเทศวิทยานุกูล..........
สาขาวิชา ....วิศวกรรมเคมี............ลายมือชื่ออาจารย์ที่ปรึกษา......สุรเทพ เขียวหอม..........
ปีการศึกษา ......2549.......

4770218821: MAJOR CHEMICAL ENGINEERING
KEY WORD: OFFSET/ DIGITAL/ PRINTING/ ENVIRONMENTAL IMPACT/ ECONOMIC

KITTIPORN NITETWITTAYANUKOOL: STUDY ON ECONOMIC AND ENVIRONMENT EFFICIENCY OF OFFSET AND DIGITAL PRINTING SYSTEMS. THESIS ADVISOR: SOORATHEP KHEAWHOM, Ph.D., 72 pp.

In generally, printing service is classified in small business entity which is located in community area. The environmental impact studied will be a necessary factor for all service providers because of wastes will directly effect to each community area. This research is studied about the environmental impact and cost of printing production by comparing between Offset printing (most favorite in Thailand) and Digital printing (new alternative for printing service). We study the different of four case studies as; 70% of printing page (black & white printing), 100% of printing page (4-color printing), 76 Pages of printing book (black & white printing) and 132 Pages of printing book (4-color printing).

According to environmental impact studied by Eco-indicator 99, we can conclude that Offset printing system will effect an environmental in term of plate making system. In average impact per one piece of production, an environmental impact will be changed by increased of printing job. At the next step, we study an environmental impact by changing the chemical element. We use the Vegetable oil instead of Benzene and result in decreasing the impact in term of Carcinogens, Respiratory of organics and Ecotoxicity while increasing an impact of Land use.

Finally we compare all aspects of environmental impact between Offset printing and Digital printing system and conclude that Offset printing system can effect higher impact than Digital printing system. Therefore, the Digital printing system is one effective alternative in order to decrease environmental impact. In production cost, Digital printing system will be cheaper than Offset printing system in low level of production. While Offset printing system will be cheaper than Digital printing system in high level of production. Moreover cost of production under Offset printing will be decreased by each production increased.

Department .....Chemical Engineering........Student's signature. KITTIPORN NITETWITTAYANUKOOL

Field of study ...Chemical Engineering......Advisor's signature. Soorathep Kheawhom

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CHAPTER I

INTRODUCTION

1.1 Importance and reason of research

Nowadays, Thailand's industry is growing rapidly. One of the growing industries is the printing industries. Over 80% of printing industries are located in an urban area not in an industrial area. Consequently, pollution emerged from there, such as air pollution and waste water have a directly impact on community. For reason mentioned above, we are interesting in studying the impact to environment resulting from the printing industry.

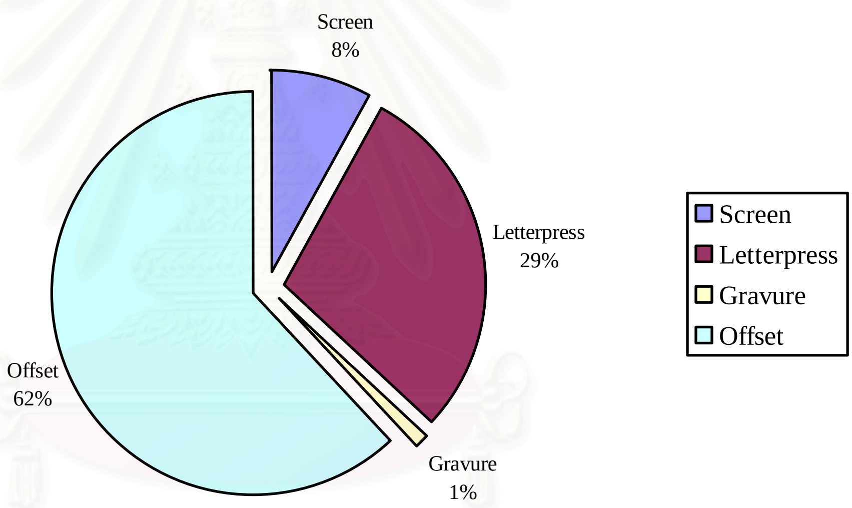

Figure 1.1: Percentage of printing industry (NPTTC, 2004).

Normally, the printing system in conventionally can be classified into four types as shown in figure 1.1. It is show that offset printing is widely used in printing industry. So, this system is presented in this work. In general, Offset printing process can be roughly divided into five steps:

- Image preparation
- Image setter
- Processing printing plates
- Printing

- Finishing

Whether or not all these steps are part of an individual print shop's operation depend on the degree of computerization and the type of lithographic press being used – web or sheet-fed. A wide variety of by-products and wastes are associated with each of these steps from waste paper and empty ink cans to less visible wastes such as vapor emissions from inks and solvents, known as volatile organic compounds (VOCs). Offset printing has many steps in process; therefore, it takes a long time to print. Moreover, building plates and films contribute to high fixed costs. So, Offset printing is not appropriate for little quantity printing.

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Today, the digital printing is a choice from among many in printing industry. Since this printing process is no need to build plate and film, it is appropriate for hasty printing. Moreover, the printing system using small chemicals causes low environmental impacts. However, a digital printing is not suitable for large quantity printing because it has high variable costs.

In the presented study, we focus on a comparison of offset printing and digital printing, in term of environmental impacts and economic issues. Life Cycle Assessment (LCA) is the most appropriate tool to achieve this purpose, allowing a global overview of this activity. So, we perform a LCA as a tool for analyzing our problems.

1.2 Research objectives

The objectives of our research are to study the life cycle of two printing systems; Offset and Digital printing systems, to analyze and to compare the direct and indirect environmental impacts, and economic performance. Moreover, locations in the life cycle contributed to environmental impacts are identified. Consequently, various options to reduce environmental impacts are proposed.

1.3 Scopes of research

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We investigate life cycles of Offset printing and Digital printing systems. The environmental and economic aspects of both systems are quantified and compared. Boundary of Offset printing system contains image settle, plate making and printing process while Digital printing system contains printing process. Eco-indicator 99 is used as an indicator in order to assess Environmental impacts. Simapro 6.0 is used as a software tool.

1.4 Contribution of Research

This work provides criteria for a selection of printing type; between Digital printing and offset printing. Moreover, it gives guideline for improvement in each step in a printing process.

1.5 Procedure Plan

1. We investigate Offset printing system and Digital printing system, and study on the research related to the printing systems.

2. The information and data of both printing systems are collected.

3. We study Life Cycle Assessment methodology and other methodologies on environmental performance evaluation.

4. Life cycle assessment on the printing systems is performed. Input/Output tables of both systems are constructed.

5. The environmental and economic performance of the printing systems are evaluated and analyzed.

6. We conclude a result from the evaluation and analysis of the environmental and economic performance of the printing systems.

7. We write the report from this study.

Table 1.1 Schedule for research

Procedure plan	**Nov.(2007)**				**Dec.(2007)**				**Jan.(2007)**				**Feb.(2007)**				**May(2007)**			
	1	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
1																				
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CHAPTER II

LITERATURE REVIEW

The graphic arts industry encompasses a wide variety of industrial endeavors, including "all arts and processes that give information by means of images printing is on surfaces". Printing is one such process, differentiated by the process used to transfer images to the substrate. Direct-to-substrate transfer processes that use raised or recessed image transfer mechanism include flexography, gravure, letterpress and screen printing. The lithography process uses a blanket cylinder to transfer or "off-set" images from the plate to the substrate, relying on oil/water chemistry to maintain an image in one plane on the image transfer plate.

Since the early 1980s the printing industry has made efforts to reduce the exposure of organic solvents. Volatile Organic Compounds (VOCs) have been contained in many of the inks, cleaners and fountain solution on the offset printing. I. W. Bartlett, A. J. P. Dalton, A. McGuinness and H. Palmer (1999) evaluated the use of vegetable oil-based cleaning agents (VCA) as an effective and less hazardous substitute for volatile organic solvents in the lithographic printing industry. The VCA have a lower environmental impact than the organic solvent cleaning agents. The main health effect is skin and mucous membrane irritation, and gloves are needed when using VCA. VCA do not affect print quality or reduce machine speed. N. Cordeiro, A. Blayo, N.M. Belgacem, A. Gandini, C. Pascoal Neto and J.-F. LeNest (2000) studied cork suberin as an additive in offset lithographic printing inks. Suberin oligomers, isolated from cork were used as additives in "waterless" and vegetable-oil ink formulations, in the range of 2-10% w/w. The tacks of pristine inks, suberin oligomers and their mixtures were determined at different temperature: the variation of this parameter as a function of time provided information about the drying kinetics of these formulations. The tack of the "waterless" ink was found to increase with the introduction of suberin, whereas that of vegetable-oil based counterparts decreased. Anne Blayo, Alessandro Gandini and Jean-Francois Le Nest (2001) studied chemical and rheological characterizations of some vegetable oils derivatives commonly used in printing inks. Chemical and rhelogical characterizations were performed in order to gain a better insight into their structure/properties relationships.

The aim of this study was therefore to improve the quality and performance of printing inks on the basis of sound scientific criteria rather than empirical notions. Hatice gecol, John F. Scamehorn, Sherril D. Christian, Brian P. Grady and Fred Riddell (2001) used surfactants to remove water based inks from plastic films. There was substantial economical and environmental incentive to remove the ink (deink) from heavily printed plastic film so that it could be reused to produce clear films. In this study, a commercial polyethylene film with water-based ink printing was deinked using different surfactants under a variety of condition. At a pH of 12, water (containing no surfactant) could achieve about 90% deinking, but less basic solutions were less effective; at a pH 10 and below, insignificant-deinking occurs. Solutions of cationic surfactant were the most effective at deinking, showing high efficiency at surfactant concentrations both above and below the critical micelle concentration (CMC) over a pH range of 5–12. Both anionic and nonionic surfactants were only effective at deinking above the CMC at very basic conditions. The cationic surfactant was most effective and the anionic surfactant was least effective, possibly because the binder was an acidic acrylate with a negative charge.

The ink vehicle plays a multiple role since it must ensure: (1) pigment wetting and transfer; (2) film-formation after printing and during drying; and finally (3) pigment protection during the life cycle of the printed material. In ink formulations, vegetable oils may be introduced unaltered or modified, in combination with other components, e.g. resins, nature. Sevim Z. Erhan and Marvin O. Bagby (1994) studied in two objects; (a) to prepare news ink based on vegetable-oil sources such as canola, cotton seed, sunflower, soybean and safflower that could met industry standards in regard to ruboff resistance, viscosity and tack, and (b) to determine the biodegradability of several types of news ink by soil microorganisms. Results showed that the vegetable oil vehicles degrade faster and more completely than commercial soybean or mineral oil based vehicles. Fermentations were allowed to proceed for 5, 12 and 25 days. Greater increase in biodegradation with time was observed for our vehicles than the commercial vehicles. In 25 days, commercial mineral-oil-based vehicles degrade 17-27%, while commercial partial soy-oil-based vehicles degrade 58-68% and our 100% soy-oil-based vehicles degrade 82-92%.

Digital technology is change many facets of business and industry today. The print production process is rapidly shifting from analogue to digital technologies as the infrastructure (or basis) for workflows. The efficiency of the production process requires the digitalization of all steps and elimination of analogue methods and materials from the process flow apart from the starting and finishing phase. Across networks, printing will be a dial tone service simple, reliable, ubiquitous, fast, and cheap. The combination of all these aspects offers very important competitive advantages to printing and publishing firms, which will be able to adapt their business processes, according to the technological and organizational framework of digital printing. This includes both the improvement of the already offered services in terms of best-value-for-money publishing and printing as well the introduction of new services. M. Glykas (2004) presented a workflow solution over the web that allows printing and publishing firms to capitalize fully the opportunities offered by digital printing. He also presented results from performance measurement and reorganization after the introduction of the D-PRINT solution to three printing and publishing firms. In 2006, Peter Gregory studied Digital photography. Digital photography was discovered by Sony in 1981. The technology struggled for many years, mainly because the electronics of the day were inadequate. This research describes the chemistry and technology of silver halide and digital photography. Particular emphasis was given to producing high-quality images by ink jet printing, the technology of choice to produce photographic prints from digital cameras.

The integration of life cycle thinking into environmental system management has started to change the way environmental problems have been seen and tackle. It point out that, if sustainable solutions to environmental problems are to be found, then they may be seek on a more global level. Today, Life Cycle Assessment (LCA) is use widely as a decision making tool; however, the methodology is still developing and a number of issues remain to be resolved. G. Rebitzer, T. Ekvall, R. Frischknecht, D. Hunkeler, G. Norris, T. Rydberg, W.-P. Schmidt, S. Suh, B.P. Weidema and D.W. Pennington (2004) studied Framework, goal and scope definition, inventory analysis and application of Life Cycle Assessment. This research introduced the LCA framework and procedure, outlines how to define and model a product's life cycle, and provides an overview of available methods and tools for tabulating and compiling associated emissions and resource consumption data in a life cycle inventory (LCI). It also discussed the application of LCA in industry and policy making. D.W. Pennington, J. Potting, G. Finnveden, E. Lindeijer, O. Jolliet, T. Rydberg and G. Rebitzer (2004) studied a current impact assessment practice of LCA. This article highlighted how practitioners and researchers from many domains had come together to provide indicators for the different impacts attributable to products in the life cycle impact assessment (LCIA) phase of life cycle assessment (LCA).

Furthermore, LCA can be applied to many processes. For example, E. Lopes, A. Dias, L. Arroja, I. Capela and F. Peraira (2003) studied application of life cycle assessment to the Portuguese pulp and paper industry. The LCA methodology was applied to Portuguese printing and writing paper in order to compare the environmental impact of the use of two kinds of fuels (heavy fuel oil and natural gas) in the pulp and paper production processes. The results of inventory analysis and impact assessment showed that the pulp and paper production processes play an important role in almost all of the analysed parameter. The substitution of heavy fuel oil by natural gas in the pulp and paper production processes seems to be environmentally positive. In 2006, Angelo Riva, Simona D’Angelosante and Carla Trebeschi studied natural gas and the environmental results of life cycle assessment. LCA was a method aimed at identifying the environmental effects connected with a given product, process or activity along its life cycle. Their research presented results of the application of LCA method in order to evaluate the environmental advantages of natural gas over other fossil fuels and to had advanced techniques for analyzing the environmental aspects of the gas industry. The evaluation of published studies and the application of the method to electricity production with fossil fuels, by using data from published databases and data collected by the gas industry, demonstrate the importance and difficulties of having reliable and updated data required for a significant LCA. Results showed that the environmental advantages of natural gas over the other fossil fuels in the final used stage increase still further if the whole life cycle of the fuels, from production to final consumption, was taken into account.

CHAPTER III

PROCESS OF PRINTING

3.1 Lithography/Offset Printing

As the currently most important technology, offset printing is explained in detail in section 3.1.1 with a description of the technology itself as well as printing plate production, examples of machinery, and how the inking and dampening units work.

In lithography the printing and non-printing parts are on the same level. The distinctive feature of the printing areas is the fact that they are ink-accepting, whereas the non-printing plate elements are ink-repellent. This effect is produced by physical, interfacial surface phenomena. Lithographic printing can be subdivided into:

- Stone lithography (direct printing process using a stone printing plate),
- Collotype (direct printing process),
- Offset printing (indirect printing process), and
- Di-litho (direct printing process with offset printing plate).

Lithography was invented by Alois Senefelder in 1796. The image to be printed was drawn on the stone with a special ink. The stone was dampened before it was inked up, after which the non-image areas of the stone surface did not take on ink.

Offset printing is the major lithographic technology. It is an indirect lithographic technology, in which the ink is first transferred from the printing plate onto a flexible intermediate carrier – the blanket – and then onto the substrate.

The advantages of offset printing include:

- Consistent high image quality-sharper and cleaner than letterpress because the rubber blanket conforms to the texture of the printing surface
- Usability on a wide range of printing surfaces in addition to smooth paper
- Quick and easy production of printing plates

- Longer plate life than on direct litho presses-because there is no direct contact between the plate and the printing surface.

The major unit operations in a lithographic printing operation include (Figure 3.1):

- Image preparation
- Image setter
- Processing printing plates
- Printing
- Finishing

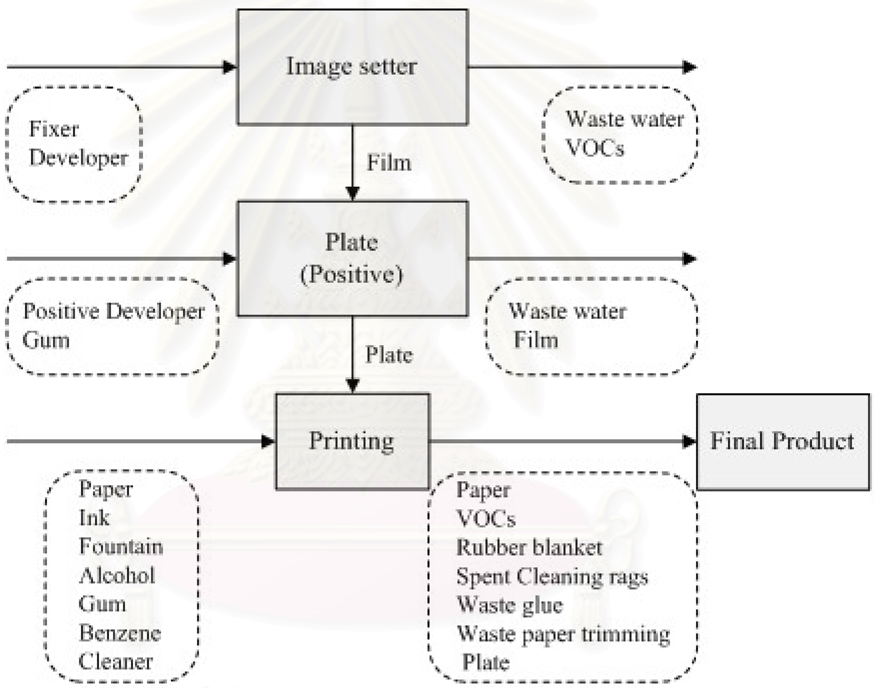

Figure 3.1 Offset printing workflow

3.1.1 Image Process (Film & Plate)

The printing industry uses photography to reproduce both art and copy, employing materials similar to those in other fields of photography. These materials include film, which has a paper, plastic or glass base covered with a light-sensitive coating (the photographic emulsion). This emulsion is usually composed of silver halide salts in gelatin.

Silver halide salts include silver chloride, silver bromide and silver iodide. Most photographic film bases are polyester.

a. Developing an image

An image is photographed and processed to photographic positive or negative. Films or plate developing solutions are alkaline and typically contain benzene derivatives like hydroquinone, pyrogallol, catechol, p-phenylene diamine, p-aminophenol, metol, amidol and pyramidal. The most common developing agents are hydroquinone and metol. In general, developing solutions also contain an accelerator, which increases the activity of the developer; a preservative, which reduces oxidation damage to the developer; and a restrainer, which inhibits the formation of “fog” on the image. Developing solutions should be in trays only slightly larger than the materials being processed and solution temperature should be maintained within ¼^{o} F of product guidelines.

b. Fixing an image

Developing action is stopped by immersing film into a fix bath of sodium thiosulfate (hypo), ammonium thiosulfate or sodium hyposulfite. These chemicals convert metallic silver to soluble complexes. Hypo, the major ingredient of fixing bath, also contains potassium alum, acetic acid and sodium sulfite. Acetic acid is used to keep pH low, which neutralizes the alkalinity of developing solutions and to stop the developing action.

Fresh fixing bath typically has a pH of 4.1, which is slightly acidic. Alkaline developer is carried over into the fixer bath on films and prints, which raises the pH slightly. When the pH reaches 5.5, the fogging preventative becomes less effective, requiring the operator to change the fix bath or lower the pH by adding more acetic acid. An acidic stop bath is often used prior to the fixer to stop the action of the developing solutions and prevent fix bath contamination.

After the negative or positive is fixed, some of the fix bath chemicals (hypo) remain in the gelatin emulsion layer. Chemicals remaining in the emulsion can react with the silver to form yellow-brown silver sulfide. To prevent this, fix chemicals are washed from the emulsion in a water bath until the hypo is dissolved. For optimum hypo is dissolved. For optimum hypo removal, water pH should be above 4.9.

Chemical are used to change image contrast by reducing or increasing the metallic deposits on the film. Reducers oxidize some of the metallic silver in the emulsion to soluble salt, and intensifiers increase silver deposit blackness by adding silver or mercury to the developed silver grains in the emulsion. Small amounts of chemicals and silver rinsed from film can accumulate in the final water bath.

c. Printing plates

The plate used in offset printing are thin (up to about 0.3 mm), and easy to mount on the plate cylinder, and they mostly have a monometal (alluminum) or, less often, multimetal, plastic or paper construction. Aluminum has been gaining ground for a longtime among the metal-based plates over zinc and steel. The necessary graining of the aluminum surface is done mechanically either by sand-blasting, ball graining, or by wet or dry brushing. Nowadays, practically all printing plates are grained in an electrolytic process (anodizing), that is, electrochemical graining with subsequent oxidation.

3.1.2 Process of Offset printing

All offset presses have three printing cylinders, as well as the inking and dampening systems. The plate cylinder, the blanket cylinder and the impression cylinder (Figure 3.2)

Lithography uses a plate, a type of plate on which the image areas are neither raised nor indented (depressed) in relation to the non-image areas. Instead the image and non-image areas, both on essentially the same plane of the printing plate, are defined by deferring physiochemical properties.

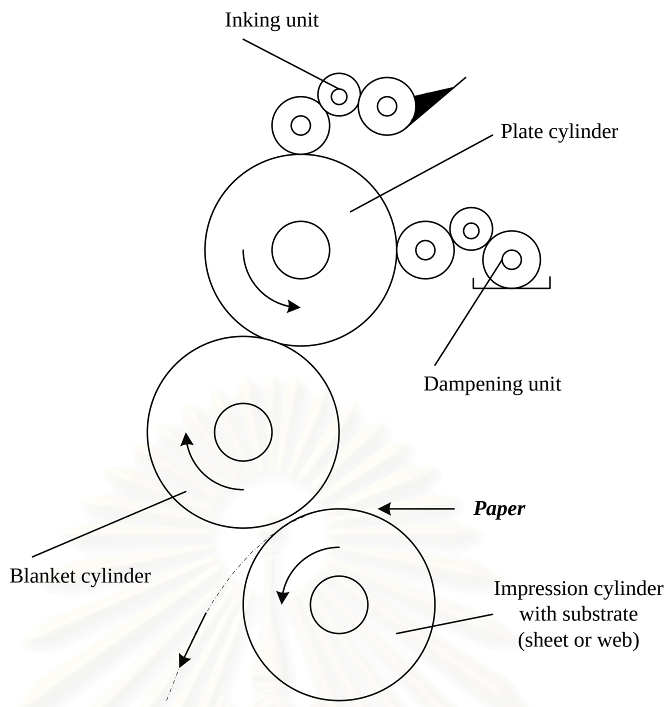

Figure 3.2 Component of Offset printing unit.

Lithography is based on the principal that oil and water do not mix (hydrophilic and hydrophobic process). Lithographic plates undergo chemical treatment that render the image area of the plate oleophilic (oil-loving) and therefore ink-receptive and the non-image area hydrophilic (water-loving). During printing, fountain (dampening) solution, which consists primarily of water with small quantities of isopropyl alcohol and other additives to lower surface tension and control pH, is first applied in a thin layer to the printing plate and migrates to the hydrophilic non-image areas of the printing plate. Ink is then applied to the plate and migrates to the oleophilic image areas. Since the ink and water essentially do not mix, the fountain solution prevents ink from migrating to the non-image areas of the plate.

As the plate cylinder rotates, the plate comes in contact with the dampening rollers first. The dampening rollers wet the plate so the non-printing areas repel ink. Then the inking rollers transfer ink to the dampened plate, where ink only adheres to the image areas. The inked image is transferred to the rubber blanket, and the substrate is printed as it passes between the blanket and impression cylinder.

3.1.3 Offset Lithographic Inks.

Printing inks used to produce an image on a substrate. Printing inks are composed primarily of three basic ingredients: pigments, the vehicle, and additives. A pigment is the solid colouring matter visible on the substrate after the printing process. The vehicle, the largest component of the ink, acts as a carrier for the pigment as well as a binder to affix the pigment to the substrate. Additives differentiate and enhance the performance of the ink and include materials such as driers, waxes, lubricants, reducing oils and solvents, body gum and binding varnish, antioxidants and anti-skinning agents, surface active agents, and resins.

The manufacture use and disposal of printing inks, which contain heavy metals, petroleum distillates, and volatile organic compounds (VOCs), are an environmental concern.

Reducing quantities of heavy metals will help protect the environment by eliminating toxic leachate and reducing possible adverse health effects. Minimizing the use of petroleum distillates conserves non-renewable resources. Reducing VOCs will improve both indoor and outside air quality, thus, improving working conditions for print shop workers, and reducing the concentration of one of the precursors of photochemical smog.

3.1.4 Fountain Solutions & Dampening System

- Direct Feed Continuous Integrated System
- Direct to Plate

Fountain solutions are applied to enhance the non-image areas ability to repel ink. Some newer fountain solutions have been developed with oxidizing chemicals which accelerate the setting and drying of inks and reduce the need for anti-set off sprays.

There are two common types of dampening systems; the direct feed continuous integrated system and direct to plate dampening system. Direct to plate dampening systems apply the fountain solution directly to the plate. Direct feed continuous integrations systems meter the fountain solution, which contains alcohol or an alcohol substitute, through the inking system. Direct feed can also act as a direct to plate dampening system and apply the fountain solution directly to the plate. This system generally uses less water, reduces make ready time and paper waste at start up.

The fountain solution acts as the water solution for the hydrophilic process of lithographic printing. Fountain solution also helps to cool the press and facilitate the ink drying. Fountain solution is applied to the dampening roller to repel ink in the non-image areas of the plate.

3.2 Digital Printing

Digital technology has changed many facets of business and industry today. Computing and communications technology has allowed companies to revolutions the manufacturing process- from producing goods and then hoping to sell them, to just-in-time production, where products are sold first and then manufactured to order, reducing waste, inventory and cost. It has also allowed them to products more in tune with individual customer's need, moving from mass production to mass customization.

Digital technology has dramatically changed the nature of the document-a document today can still be a sheet of paper or book, but is more likely to be an electronic file, a spreadsheet, presentation, scanned image or a clip with video and music. Computers, desktop publishing applications, digital imaging and printer have allowed millions of people to create documents on their desktop that used to take a team of people weeks to develop.

There are numerous digital printing technologies available, including inkjet, electro-photography with dry or liquid toner, thermal transfer, ionography and magnetography. Even traditional offset presses with direct imaging (or DI) are promote as "digital presses". What truly distinguishes digital printing from traditional printing is the ability to print every page differently. This is something that offset presses-including DI presses-cannot do. Offset presses can only print exact replicas of the same sheet, again and again.

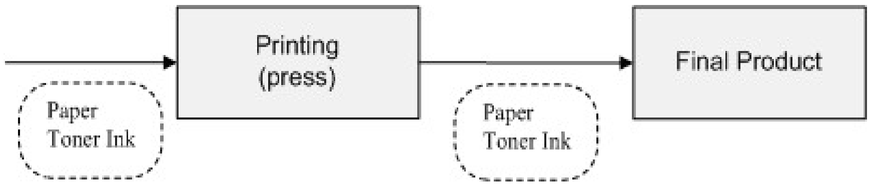

Figure 3.3 Digital printing workflow

The entry process for the production of printed document can be broken-down into three phases: prepress (which includes all steps after the design is completed up to the point where the job is printing), press or printing (the printing phase), and final product or finishing (all the steps required to finish the job after printing and before distribution), as shown in figure 3.3.

3.2.1 Process of Digital printing

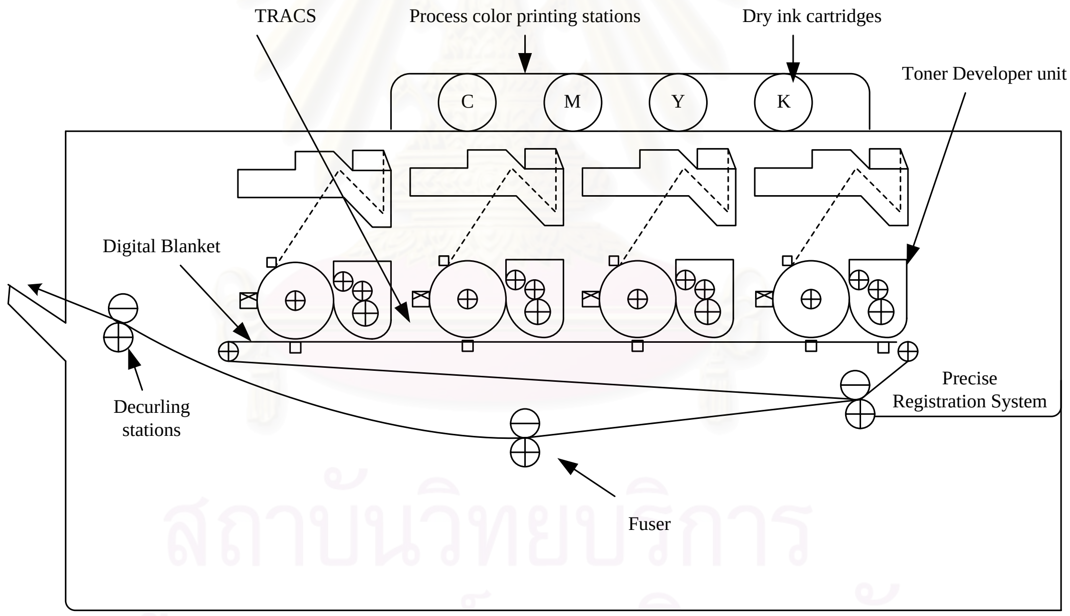

Figure 3.4 digital printing systems

Process color printing station

Inside the digital printing system there four printing station-one for each process colors: cyan (C), magenta (M), yellow (Y) and black (K). Each station houses extra-large cartridges that hold a mixture of dry ink and developer. The printing station with fresh dry ink and developer, which ensures a more consistent image quality over longer periods of time and though longer runs.

Digital Blanket

The Digital Blanket passes under the four printing stations where the image is transferred to the blanket. The four colors of the image are assembled on the blanket - one on top of another in perfect register - and then transferred to the paper in single pass when the blanket passes under a pressure roller. The uniform, flat surface of the Digital Blanket reduces image quality defects and extends the range of stock that can be reliably supported.

Fuser

The imaged paper then travels toward the fuser, crossing two vacuum transports which keep stocks moving along smoothly. The fuser is another technological innovation that ensures each image is fused properly to the stock. It consists of a roller and a belt that ensures stocks stay against the heated roller for the longest possible time for a complete fix of the image. A long dwell time is especially important for heavy stocks and jobs with heavy area coverage to fuse well, and to compensate for the increased speed of printing of the press.

TRACS (Toner Reproduction Auto Correction System)

TRACS automatically measures 16 levels of density and color, and makes adjustments on the fly. TRACS works by placing CMYK density patches on the Digital Blanket between pages as they circulate through the machine. These patches are read by built-in auto density control sensors, and any quality adjustments are made on the fly. The result is consistent and reliable color from start to finish.

Precise Registration System

Important to total high quality output is image to page registration. On the Digital printing System, stock is passed over three aligner transport rolls which de-skew the stock by applying the appropriate amount of pressure based on the substrate's weight and size. A registration roll then centers the stock to the image on the Digital Blanket. Centering the stock cuts down on sheet-to sheet and front-to-back registration errors by half. Two timing registration sensors also regulate the speed of the Digital Blanket for more accurate, more consistent image-to-blanket registration and image-to-page registration.

Decurling devices

When dry ink is fused to paper, especially with heavy coverage, there is a natural tendency for the paper to curl. To eliminate curling, the stock passes through two of three decurling devices. The devices look at the stock, the print coverage, and whether the job is simplex or duplex (when the stock is duplexed, it passes through all three decurling devices). The devices remove curl and produce flat, uniform output that run smoothly through the press.

3.2.2 Digital printing ink.

Special inks are used for digital printing. These may be powder or liquid toners, which may very in structure according to their composition, and contain the colorant in the from of pigments. The ink is the fundamental and decisive element for the impression. Inking is done via systems which transfer the fine toner particles, approximately 8 μm in size, with out contact to the photoconductor drum. The toner charge is configured in such a way that the charged areas of the photoconductor surface accept the toner. Therefore, after inking, the latent image on the photoconductor drum becomes visible where the toner is applied.

a. toner transfer (printing)

The toner may be transferred directly onto the paper, although in some case it may also be transferred via intermediate systems, in from of a drum or a belt. Transfer mostly takes place directly from the photoconductor drum to the substrate. To transfer the charged toner particle from the drum surface to the paper, electrostatic forces are generated via a charge source in the nip and it is these forces, supported by the contact pressure between the drum surface and the paper, that transfer the particle to the paper.

CHAPTER IV

LIFE CYCLE ASSESSMENT (LCA)

Sustainable development require methods and tools to measure and compare the environmental impacts of human activities for the prevision of goods and services (both of which are summarized under the term "product"). Environmental impacts include those from emission into the environment and through the consumption of resources, as well as other intervention (e.g. land use) associated with providing products that occur when extracting resources, producing materials, manufacturing the products, during consumption/use, and at the product' end –of –life. These emissions and consumptions contribute to a wide range of impacts, such as climate change, stratospheric ozone depletion, tropospheric ozone (smog) creation, acidification, toxicological stress on human health and ecosystems, the depletion of resource, water use, land use, and noise-among other. A clear need, therefore, exists to be proactive and to provide complimentary insights, apart from current regulatory practices, to help reduce such impacts. Practitioners and researchers from many domains come together in life cycle assessment (LCA) to calculate indicators of the aforementioned potential environmental impacts that are linked to products-supporting the identification of opportunities for pollution prevention and reductions in resource consumption while taking the entire product life cycle into consideration.

4.1 What is LCA?

Life cycle assessment (LCA) involves the evaluation of some aspects – often the environmental aspects – of a product system through all stages of its life cycle. Sometimes also called "life cycle analysis", "life cycle approach", "cradle to grave analysis" or "Ecobalance", it represents a rapidly emerging family of tools and techniques designed to help in environmental management and, longer term, in sustainable development.

4.2 The structure and components of LCA

While advances continue to be made, international and draft standards of the ISO 14040 series are, in general, accepted as providing a consensus framework for LCA:

- International Standard ISO 14040 (1997) on principles and framework.
- International Standard ISO 14041 (1998) on goal and scope definition and inventory analysis.
- International Standard ISO 14042 (2000) on life cycle impact assessment.
- International Standard ISO 14043 (2000) on life cycle interpretation.

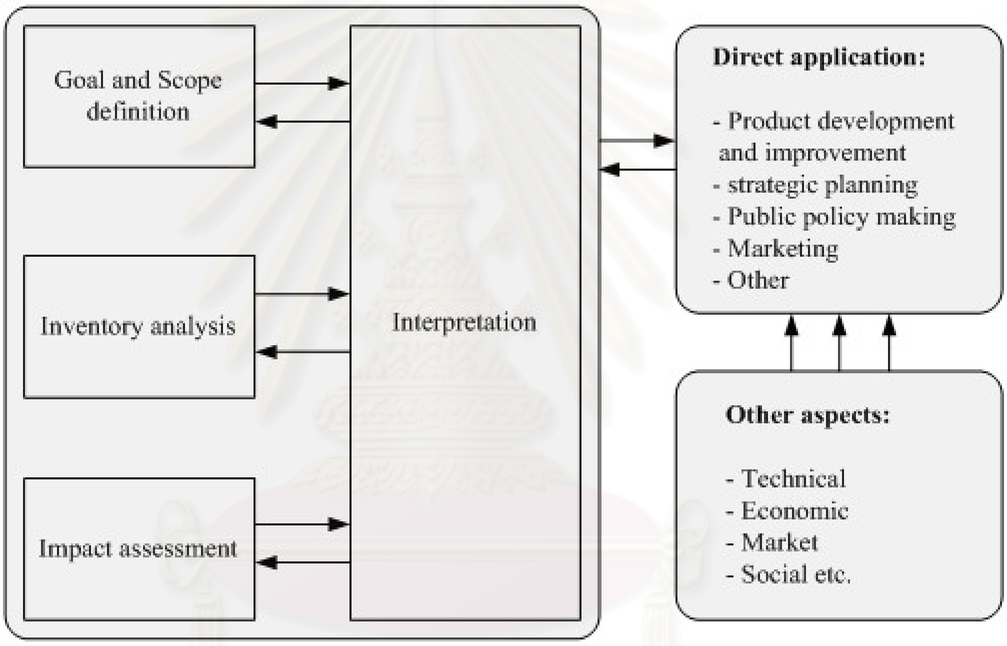

Figure 4.1: Life cycle assessment framework (based on ISO 14040, 1997).

As shown in Figure 4.1 the life cycle assessment framework is described by four phase;

- Goal and scope definitions
- Inventory analysis
- Impact assessment
- Interpretation

The double arrows between the phases indicate the interactive nature of LCA as illustrated by the following examples: when doing the impact assessment it can become clear that certain information is missing which means that the inventory analysis must be improved, or the interpretation of the results might be insufficient to fulfill the needs required by the goal and scope definition must be revised.

4.3 Goal and scope definition

Goal and scope definition is the first phase in a life cycle assessment containing the following main issues:

- Goal
- Scope
- Functional unit
- System boundaries
- Data quality
- Critical review process

The definition of the goal and scope is the critical parts of an LCA due to the strong influence on the result of the LCA.

4.3.1 Goal

The goal definition also has to define the intended use of the results and users of the results. The practitioner, who has to reach the goal, needs to understand the detailed purpose of the study in order to make proper decisions throughout the study. Examples of goals of a life cycle assessment are:

- To compare two or more different products fulfilling the same function with the purpose of using the information in marketing of the products or regulating the use of the products.
- To identify improvement possibilities in further development of existing products or in innovation and design of new products

The goal definition determines the level of sophistication of the study and the requirements to reporting. The target group of the LCA study is also important to have in mind in the choice of reporting method.

4.3.2 Scope

In definition the scope of and life cycle assessment study, the following items shall be considered and clearly described:
The functions of the system, or in the case of comparative studies, system;

- the functional unit;
- the system to be studied;
- the system boundaries;
- allocation procedures;
- the type of impact and the methodology of impact assessment and subsequent interpretation to be used;
- data requirement;
- assumptions;
- limitation;
- the initial data quality requirements;
- the type of critical review, if any;
- the type and format of the report required for the study

The scope should be sufficiently well defined to ensure that the breadth, the depth and the detail of the study are compatible and sufficient to address the stated goal.

4.3.3 Functional unit

Definition of the functional unit or performance characteristics is the foundation of an LCA because the functional unit sets the scale for comparison of two or more products including improvement to one product (system). All data collected in the inventory phase will be related to the functional unit. When comparing different products fulfilling the same function, definition of the functional unit is of particular importance.

One of the main purposes for a functional unit is to provide a reference to which the input and output data are normalized. A functional unit of the system shall be clearly defined and measurable. The result of the measurement of the performance is the reference flow. Comparisons between systems shall be done on the basis of the same function, measured by the same functional unit in the form of equivalent reference flows.

4.3.4 System boundaries

The system boundaries define the processes and the inputs and outputs to be taken into account in the LCA. The input can be the overall input to a production as well as input to a single process and the same is true for the output.

The initial system boundary defines the unit process which will be included in the system to be modeled. Ideally, the product system should be modeled in such a manner that the inputs and outputs at its boundary are elementary flows. However, as a practical matter, there typically will not be sufficient time, data, or resources to conduct such a comprehensive study. Decisions must be made regarding which unit processes will be modeled by the study and the level of detail to which these unit processes will be studied. Resources need not be expanded on the quantification of minor or negligible inputs and outputs that will not significantly change the overall conclusions of the study. Decisions must also be made regarding which releases to the environment will be evaluated and the level of detail of this evaluation. The decision rules used to assist in the choice of inputs and outputs should be clearly understood and described.

4.3.5 Data quality

The quality of the data used in the life cycle inventory is naturally reflected in the quality of the final LCA. The data quality can be described and assessed in different ways. It is important that the data quality is described and assessed in systematic way that allows others to understand and control for the actual data quality.

Initial data quality requirements shall be established which define the following parameter:

- Time – related coverage: the desired age (e.g. within last 5 years) and the minimum length of time.
- Geographical coverage: geographic area from which data for unit processes should be collected to satisfy the goal of the study (e.g. local, regional, national, continental, global).
- Technology coverage: nature of the technology mix

4.3.6 Critical review process

The purpose of the critical review process is to ensure the quality of the life cycle assessment. The preview can be either internal, external or involve interested parties as defined within the goal and scoping definition. The critical review process shall ensure that:

- The method used to carry out the LCA are consistent with this international standard;
- The methods used to carry out the LCA are scientifically and technically valid;
- The data used are appropriate and reason able in scientifically to the goal of the study;
- The interpretations reflect the limitations identified and the goal of the study;
- The study report is transparent and consistent.

4.4 Inventory analysis

Inventory analysis is the second phase in a life cycle containing the following main issues;

- Data collection
- Refining system boundaries
- Calculation
- Validation of data
- Relating data to the specific system
- Allocation

This section includes a short presentation of software tools that can be a useful help in structuring and calculating the inventory data. The inventory analysis and the tasks to be fulfilled can obviously be supported by a flow sheet for the considered product.

4.4.1 Data collection

Inventory analysis involves data collection and calculation procedures to quantify relevant inputs and outputs may include the use of resources and releases to air, water and land associated with the system. Interpretation may be drawn from these data, depending on the goals and scope of the LCA. These data also constitute the input to the life cycle impact assessment.

The process of conducting an inventory analysis is iterative. As data are collected and more is learned about the system, new data requirements or limitations may be identified that require a change in the data collection procedure so that the goals of the study will still be met. Sometime, issues may be identified that require revision to the goal or scope of the study.

The qualitative and quantitative data for inclusion in the inventory shall be collected for each unit process that is included within the system boundaries. The procedures used for data collection may very depending on the scope, unit process or intended application of the study. Data collection can be a resource intensive process. Practical constraints on data collection should be considered in the scope and documented in the report.

4.4.2 Refining system boundaries

The system boundaries are defined as a part of the scope definition procedure. After the initial data collection, the system boundaries can be refined e.g. as a result of decisions of exclusion life stages or sub-system, exclusion of material flows or inclusion of new unit processes shown to be significant according to the sensitivity analysis.

4.4.3 Calculation procedures

No formal demands exist for calculation in life cycle assessment except the described demands for allocation procedures. Due to the amount of data it is recommended as a minimum to develop a spreadsheet for the specific purpose. A number of general PC-program/software for calculation are available e.g. spreadsheet/ spreadsheet application, together with many software programs developed specially for life cycle assessment. The appropriate program can be chosen depending on the kind and amount of data to be handled.

4.4.4 Validation of data

The validation of data has to be conducted during the data collection process in order to improve the overall data quality. Systematic data validation may point out areas where data quality must be improved or data must be found in similar processes or unit processes.

Data from similar processes or unit processes do often have a lower overall data quality. This can be reflected in the data quality index for the specific data-set.

4.4.5 Relating data

For each unit process, an appropriate reference flow shall be determined (e.g. one kilogram of material or one mega joule for energy). The quantitative input and output data of the unit process shall be calculated in relation to this reference flow.

Based on the refined flow chart and systems boundary, unit processes are interconnected to allow calculations of the complete system. This is accomplished by normalizing the system to the functional unit and then normalizing all upstream and downstream unit processes accordingly. The calculation should result in all system input and output data being referenced to the functional unit. Care should be taken when aggregating the inputs and outputs in the product system. The level of aggregation should be sufficient to satisfy the goal of the study.

Data categories should only be aggregated if they are related to equivalent substances and to similar environmental impacts. If more detailed aggregation rules are required, they should be justified in the goal and scope definition phase of the study or this should be left to a subsequent impact assessment phase.

4.4.6 Allocation and recycling

When performing a life cycle assessment of a complex system, it may not be possible to handle all the impacts and outputs inside the system boundaries. This problem can be solved either by:

- Expanding the system boundaries to include all the inputs and outputs, or by
- Allocating the relevant environmental impacts to the studied system

4.5 Impact assessment

Impact assessment is the third phase in a life cycle assessment containing the following main issues:

- Category definition
- Classification
- Characterization
- Valuation/weighting

The framework for LCA is defined as follows (ISO, 1997):

The life cycle impact assessment framework and its procedure should be transparent and provide the flexibility and practicality for this wide range of application. A large range in the levels of effort and intensity of the analysis are possible with LCA for different applications. In addition, impact assessment should be effective in terms of cost and resources used.

The distinction into different elements is necessary for several reasons:

- Each element represents a different specific procedure;
- All element are not required for all applications;
- Method, assumptions and value-choices can be made more transparent and can be documented and review;
- The effects of method, assumptions, and value-choices on the results can be demonstrated.

4.5.1 Category definition

The aim of this section is to provide guidance for selecting and defining the environmental categories.

Numerous environmental categories have been proposed for life cycle impact assessment. Most studies will select from these previous efforts and will not define their own categories. The selection of categories should be consistent with the goal and scope of the study. This section should not be used to avoid or disguise environmental issues or concerns. The completeness and extent of the survey of categories is goal and scope dependent.

The impact categories considered are;

- Carcinogens
- Respiratory organics
- Respiratory inorganics
- Climate change
- Radiation
- Ozone layer
- Ecotoxicity
- Acidification/ Eutrophication
- Land use
- Minerals

4.5.2 Classification

Classification is a qualitative step based on scientific analysis of relevant environmental process. The classification has to assign the inventory input and output data to potential environmental impacts i.e. impacts categories. Some outputs contribute to different impact categories and therefore, they have to be mentioned twice. The resulting double counting is acceptable if the effects are independent of each other whereas double counting of different effects in the same effect chain is not allowed.

4.5.3 Characterization

The characterization of characterization is to model categories in terms of indicators, and, if possible, to provide a basis for the aggregation of the inventory input and output within the category. This is also done in terms of the indicator to represent an overall change or loading to that category. The result of category indicators represents initial loading and resource depletion profile.

Each category should have a specific model for the relationship between the input and output data and the indicator. The model should be based on scientific knowledge, where possible, but may have simplifying assumptions and value-choices. The representative ness and accuracy of each model depends on several factors, such as spatial and temporal compatibility of the category, with the inventory. The relationship between the inventory input and output data and the category indicator is normally strong. The relationship between the indicator and the endpoint is usually weaker and may be mainly qualitative.

4.5.4 valuation/weighting

Weighting aims to rank, weight, or possible, aggregate the results of different life cycle impact assessment categories in order to arrive at the relative importance of these different results. The weighting process is not technical, scientific or objective as these various life cycle impact assessment results e.g. indicator for greenhouse gases or resource depletion, are not directly comparable. However, weighting may be assisted by applying scientifically-based analytical techniques. Weighting may be considered to address three basic aspects:

- To express the relative preference of an organization or group of stakeholders based on policies, goals or aims, and personal or group opinions or beliefs common to the group;
- To ensure that process is visible, documental and reportable, and
- To establish the relative importance of the results is based on the state of knowledge about these issues.

4.6 Interpretation

Interpretation is the fourth phase in LCA containing the following main issues (ISO, 1997):

- Identification of significant environmental issues
- Evaluation
- Conclusions and recommendations

The different elements are explained in relation to the ISO standard. The ISO standard on interpretation is the least developed part of the standard and therefore the description below is expected to be revised when the standard is finally approved.

LCA interpretation is a systematic procedure to identify, qualify, check, and evaluate information from the conclusions of the inventory analysis and/or impact assessment of a system, and present them in order to meet the requirements of the application as described in the goal and scope of the study.

Life cycle interpretation is also a process of communication designed to give credibility to the results of the more technical phases of LCA, namely the inventory analysis and the impact assessment, in a form which is both comprehensible and useful to the decision maker.

Interpretation is performed in interaction with the three other phases of the LCA. If the result of the inventory analysis or the impact assessment is found not to fulfill the requirement defined in the goal and scoping phase, the inventory analysis must be improved by e.g. revising the system boundaries, further data collection etc. followed by an improved impact assessment. This iterative process must be repeated until the requirements in the goal and scoping phase are fulfilled as can be described by the following steps:

1. Identify the significant environmental issues.
2. Evaluate the methodology and results for completeness, sensitivity and consistency
3. Check that conclusions are consistent with the requirement of the goal and scope of the study, including, in particular, data quality requirements, predefined assumptions and values, and application oriented requirements.
4. If so, report as final conclusions. If not return to step 1 or 2.

This procedure has to be repeated until 3 are fulfilled.

The aim if interpretation is to reduce the number of quantified data and/or statements of the inventory analysis and/or impact assessment to the key results to facilitate a decision making process based on, among other inputs, the LCA study. This reduction should be robust to uncertainties in data and methodologies applied and give an acceptable coverage and representation of the preceding phases.

CHAPTER V

LIFE CYCLE ASSESSMENT OF PRINTING

Life cycle assessment (LCA) is a methodological framework for estimating and assessing the environmental impacts attributed in its life cycle such as climate change, stratospheric ozone depletion, tropospheric ozone (smog) creation, eutrophication, acidification, toxicological stress on human health and ecosystem, the depletion of resource, water use, land use, noise and others.

In this research, we focus on a comparison between Offset printing system and Digital printing system in terms of environmental impact and economic issues. We consider 4 case studies as follows:

Case 1: 1 page 1 color (Black)

Functional unit is one piece of paper (70% black & white printing per page)

Case 2: 1 page 4 colors (Cyan, Magenta, yellow and Black)

Functional unit is one piece of paper (100% 4-color printing per page)

Case 3: 1 book 1 color (Black)

Functional unit is one piece of book (76 pages black & white printing)

Case 4: 1 book 4 colors (Cyan, Magenta, yellow and Black) 132

Functional unit is one piece of book (132 pages 4-color printing)

To evaluate the environmental impacts of Offset and Digital printing system, we used Eco-Indicator 99 as an indicator. LCA software tool, SimaPro 6.0 was used for data analysis. The results obtained is presented by single score graph of all impacts. Environmental impacts can be categorized into three groups as following:

1. **Human Healthy.** This category consists of Carcinogenic, Respiration of organic substance and inorganic substance, Climate change and Ozone depletion.
2. **Ecosystem**. This category consists of Acidification & Eutrophication and Ecotoxicity.
3. **Resource depletion**. This category consists of Mineral.

5.1 Life Cycle Assessment of Offset printing

In the first step, data collection was performed. The Offset printing system can be divided into three processes as image setter, plate making and printing process. In each process, the chemical required are listed as following:

- Image setter uses materials as fixer and Developer
- Plate making uses materials as Positive Developer and Gum
- Printing uses materials as Ink, Fountain solution, Gum, Benzene and Cleaner

Input-output data collected from selected printing house are used for analysis and evaluation of environmental impacts. The components of all chemical used in the off-set printing process are listed Table 5.1. Eco-Indicator 99 was then used to analyze and assessed the impacts.

- The major impacts on three categories (Human healthy, Ecosystem and Resource depletion) are shown on Figs 5.1-5.4
- The environmental impacts from impacts categories such as Carcinogens, Respiratory of organics, Respiratory of inorganics, Climate change, Radiation, ozone layer, Ecotoxicity, Acidification & Eutrophication, Land use and Minerals, are shown on Figs 5.5-5.8.
- A comparison of overall environmental impacts in each cases, is shown on Figs 5.9-5.10.

Table 5.1: Chemical Data in Offset printing process

Operation	Chemical name	Chemical entity	% by weight
Image setter	Fixer	Acetic acid	3
		Sodium thiosulphate	3
		Sodium acetate	5
		Sodium sulfite	5
		Ammonium thiosulfate	32
		Water	52
	Developer	Potassium carbonate	11
		Potassium sulfite	8
		Sodium sulfite	8
		Hydroquinone	5
		Diethyleneglycol	5
		Water	63
Plate	Developer	Potassium carbonate	11
		Potassium sulfite	8
		Sodium sulfite	8
		Hydroquinone	5
		Diethyleneglycol	5
		Water	63
	Gum		
Print	Fountain Solution	Isopropanol	99.8
	Ink	Pigment	34
		Benzene	8
		Alkyd varnish	41.5
		Toluene	13.5
	Gum		
	Benzene		
	Cleaner		

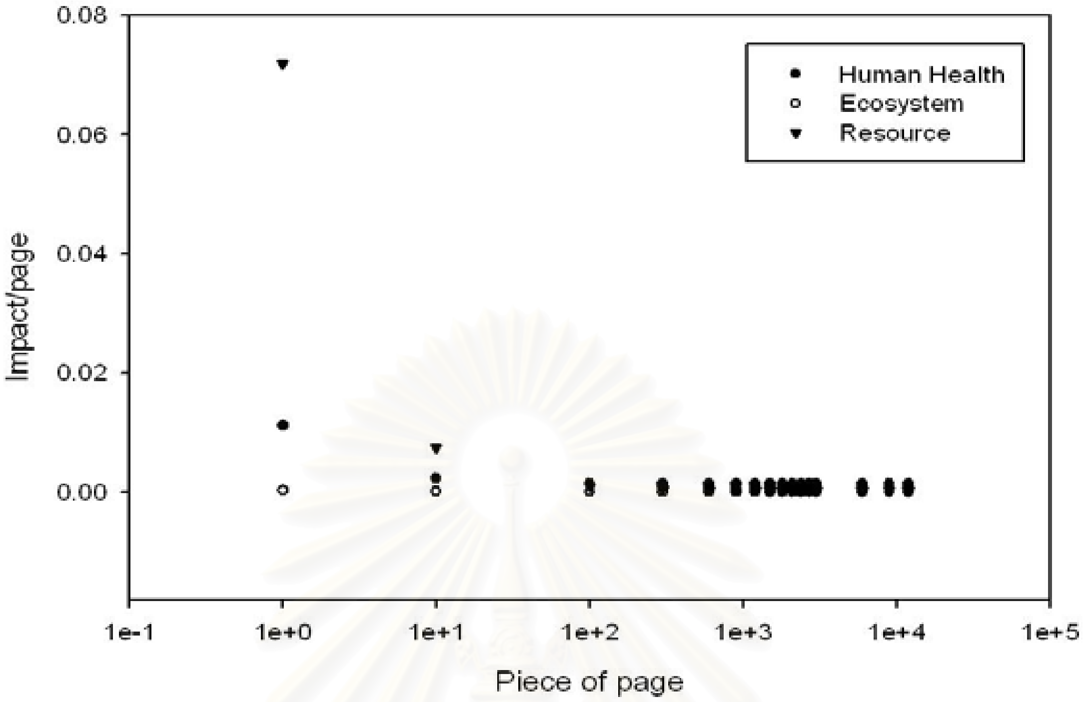

Figure 5.1: A major environmental impact of Offset printing system in terms of Human Healthy, Ecosystem and Resource depletion (Case 1)

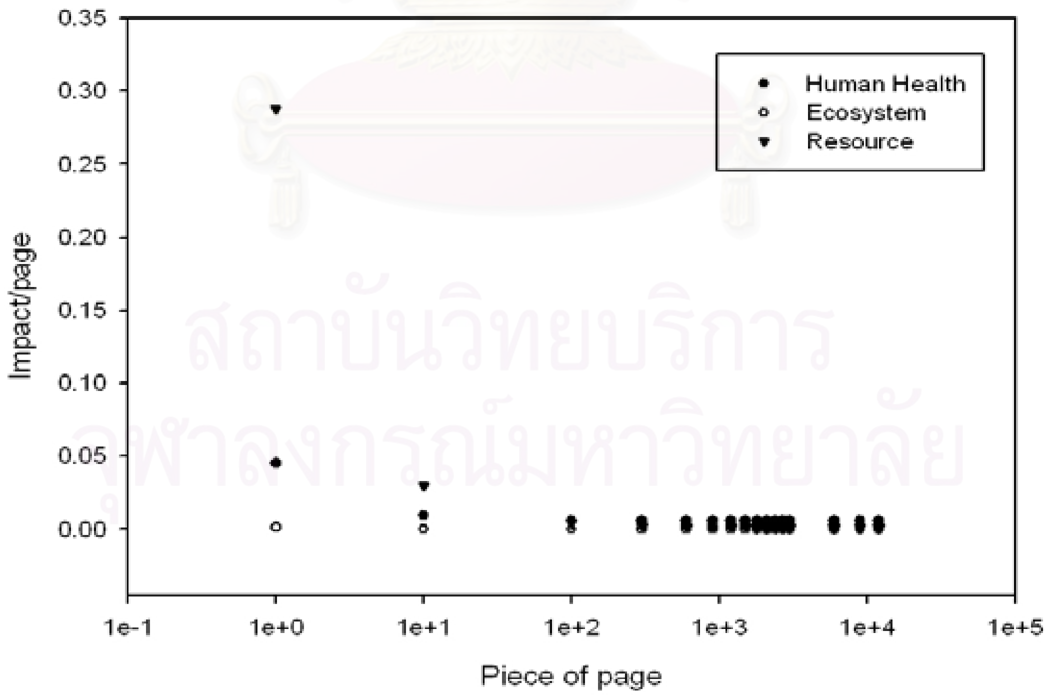

Figure 5.2: A major environmental impact of Offset printing system in terms of Human Healthy, Ecosystem and Resource depletion (Case 2)

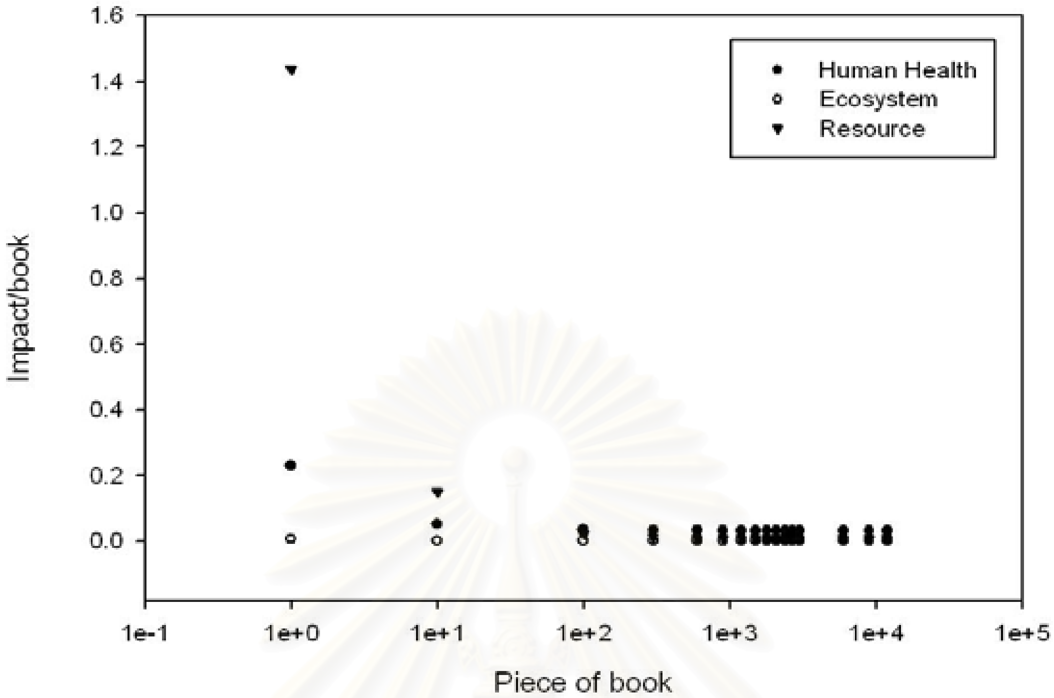

Figure 5.3: A major environmental impact of Offset printing system in terms of Human Healthy, Ecosystem and Resource depletion (Case 3)

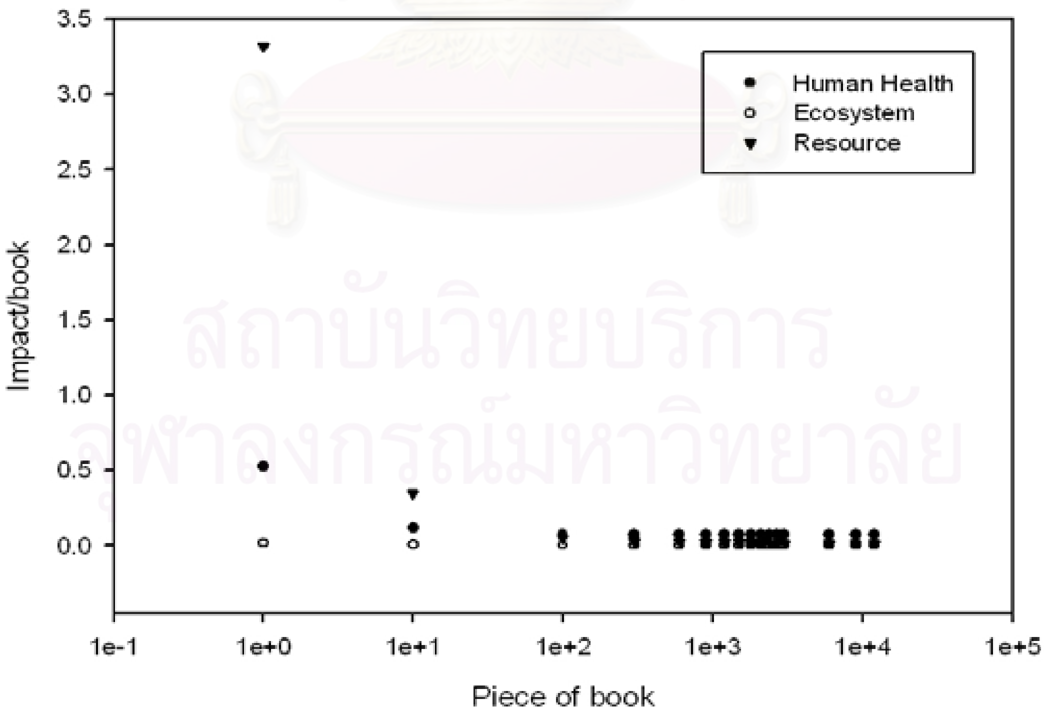

Figure 5.4: A major environmental impact of Offset printing system in terms of Human Healthy, Ecosystem and Resource depletion (Case 4)

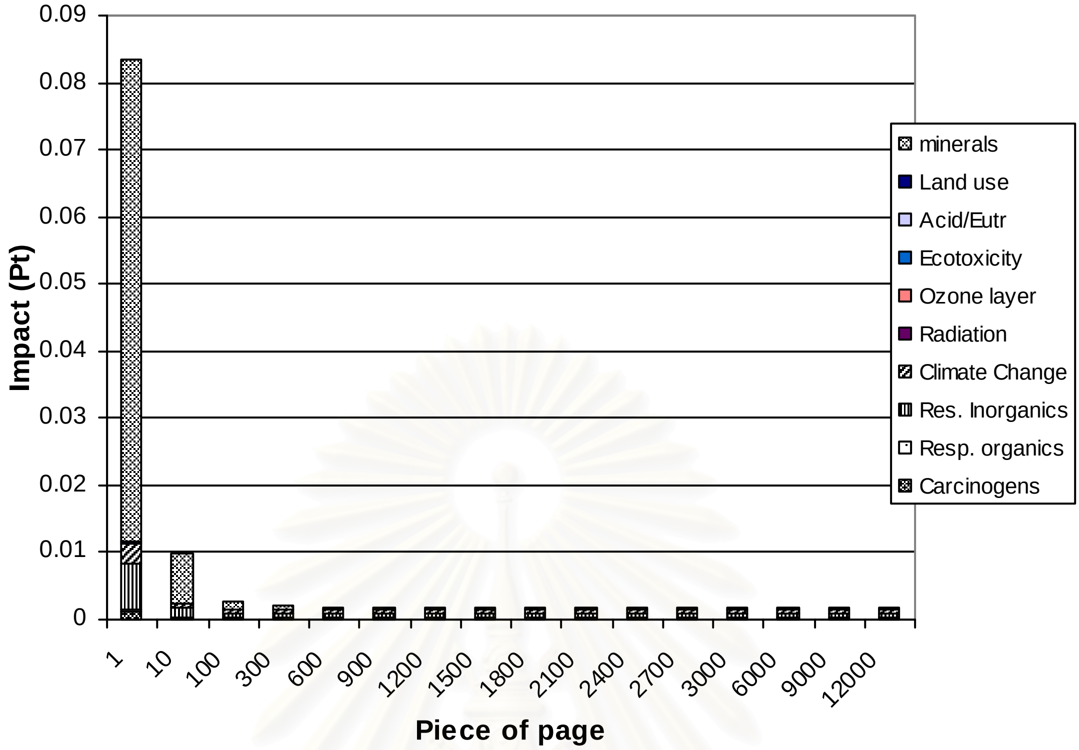

Figure 5.5: Minor environmental impact under Offset printing system (Case 1)

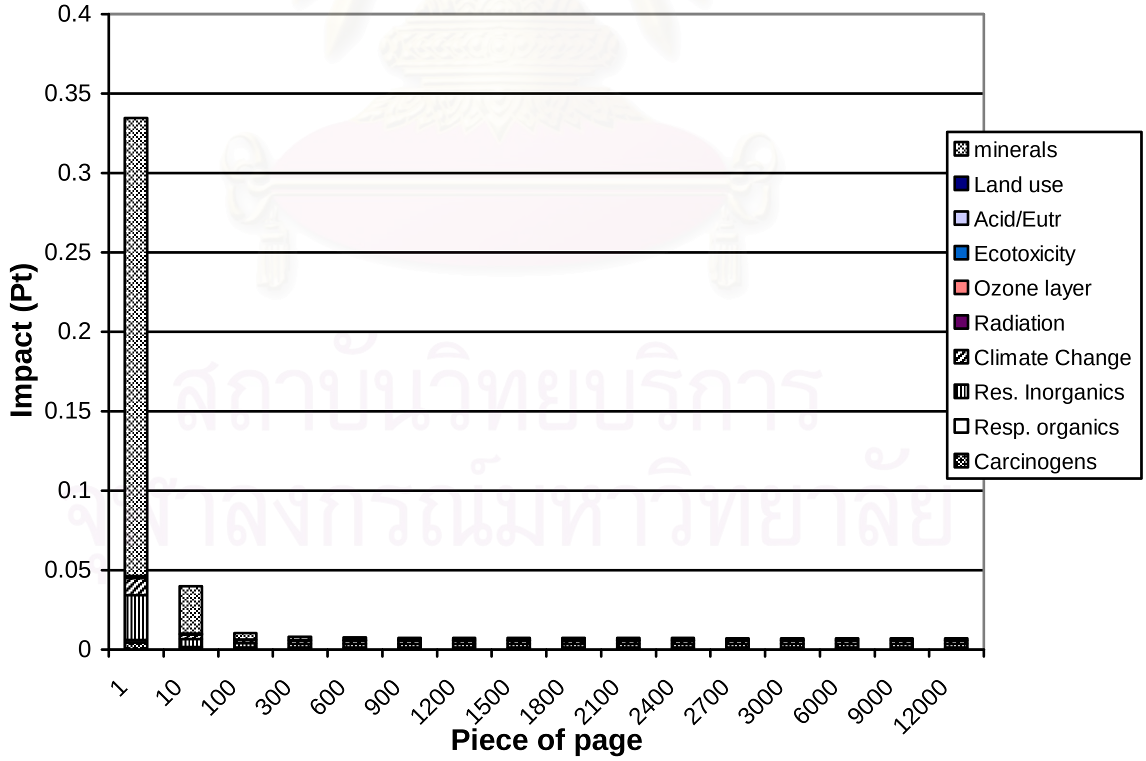

Figure 5.6: Minor environmental impact under Offset printing system (Case 2)

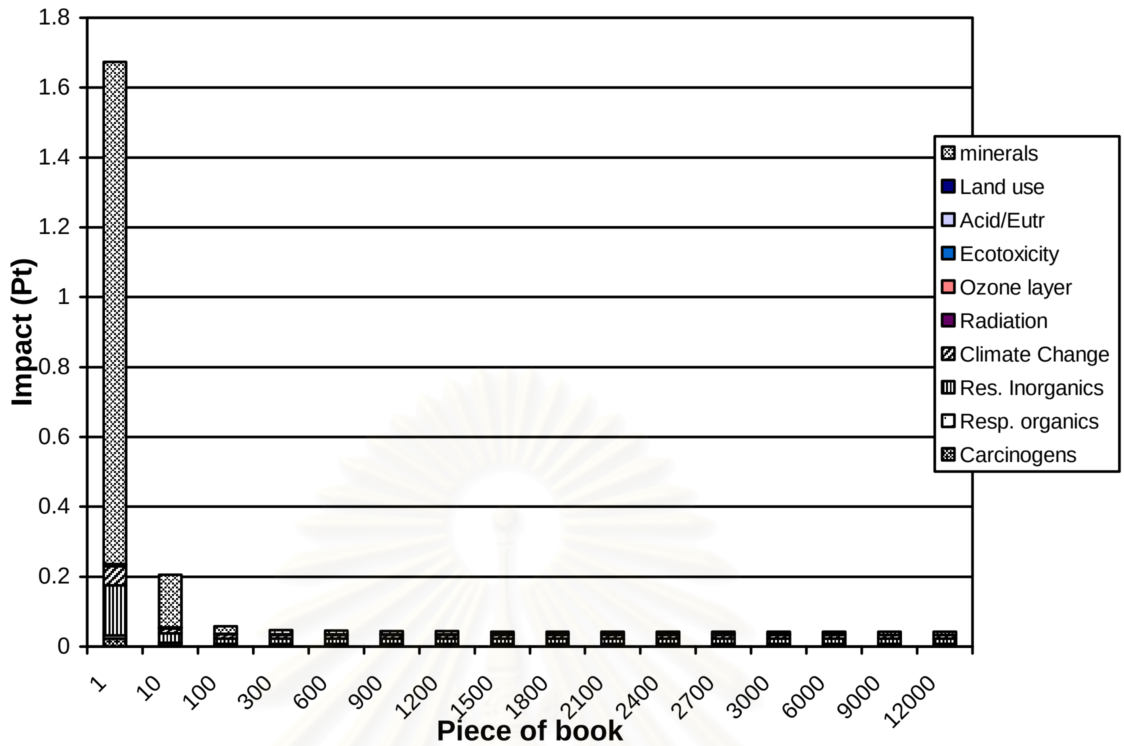

Figure 5.7: Minor environmental impact under Offset printing system (Case 3)

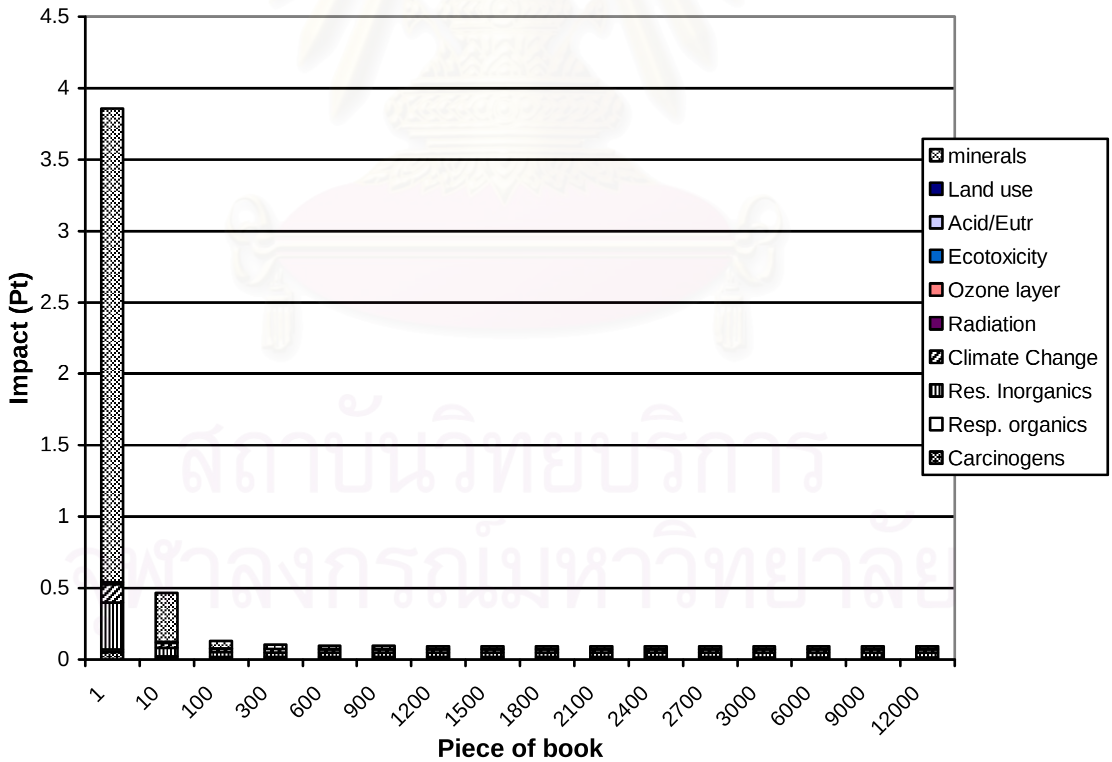

Figure 5.8: Minor environmental impact under Offset printing system (Case 4)

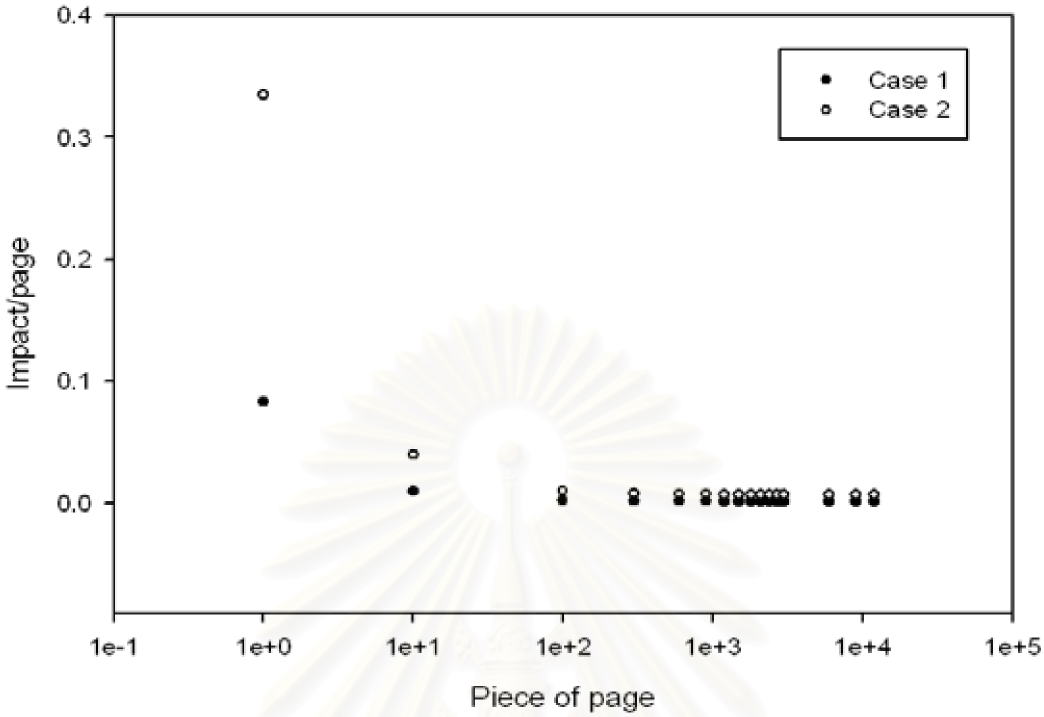

Figure 5.9: Caparison of environmental impact on Offset printing system among case 1 and case 2

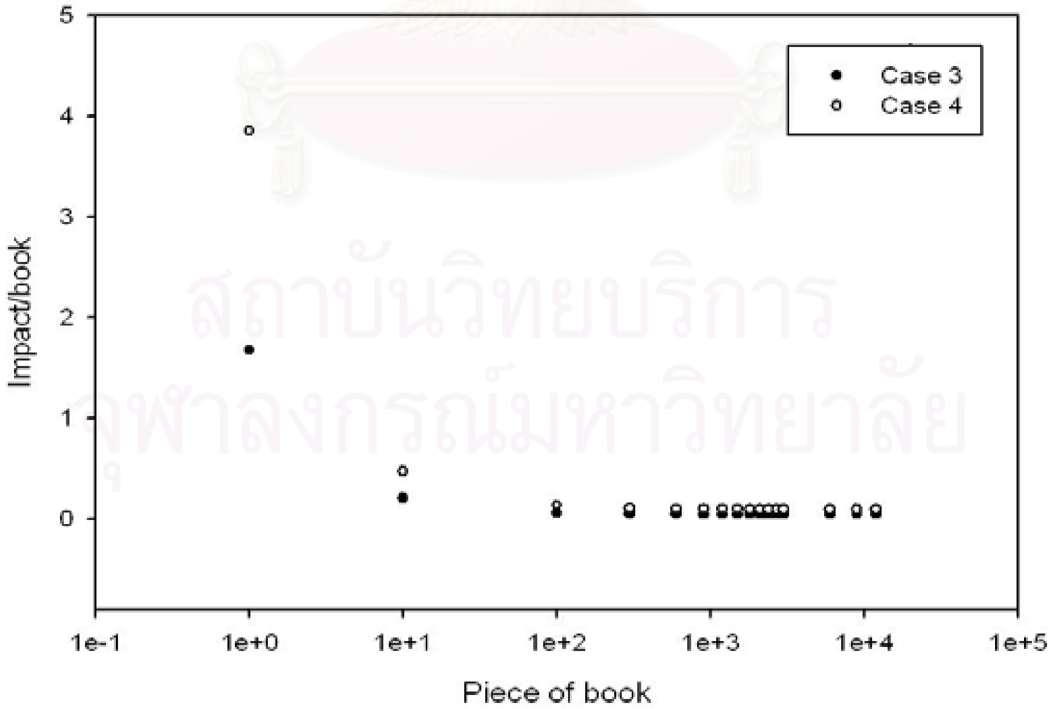

Figure 5.10: Caparison of environmental impact on Offset printing system among case 3 and case 4

5.1.1 Result in studying LCA under Offset printing system

Figures 5.1-5.4 present major environmental impacts of Offset printing system. In all cases, there is a similar tendency for the impacts to reduce for an increasing of the number of page printed. The highest impact is on Resource depletion, Human Health and Ecosystem, respectively. The reason is due to the plate making process. The plate is made of Aluminum and glaze, covered by silver halide. In comparison, the impacts resulted from other processes tend to decrease for an increasing of the number of page printed.

Figures 5.5-5.8 present minor environmental impacts of Offset printing system. The highest impact is on Respiratory of inorganic, Climate change, Carcinogens and Respiratory of organics, respectively. The reason is chemical evaporating in printing process. Moreover in each step of production will be affect the impact in different aspects. Fixer and Developer solution create an impact in term of Respiratory of inorganic, Climate change, Carcinogens and Respiratory of organics while plate processing creates an impact on Minerals. However Offset printing system affects environmental impact at low level of Land use, Radiation, Ozone layer, Ecotoxicity and Acidification & Eutrophication.

We compared the environmental impacts between one-color printing and 4-color printing system. Figure 5.9 (1 printing paper) and Fig. 5.10 (a piece of printing book) show that printing case 2 has more environmental impacts than that of case 1, and printing case 4 has more impacts than that of case 3. Because, 4-color printing (case 2 & 4) requires higher quantity of ink, film and plate than in case of one-color printing (case 1 & 3).

5.2 Life Cycle Assessment of Digital printing

Digital printing system is a new interesting alternative in printing service industry. The system consists of only one process. It is appropriated for immediately printing job. We studied environmental impacts of digital printing in four case studies. All chemical's component data used in Digital printing system are listed in Table 5.2.

Table 5.2: Chemical Data in Digital printing process

Chemical name	Chemical Entity	% by weight
Toner ink	Styrene/butadiene copolymer	75-85
	Iron oxide	10-20
	pigment	<5

Input-output data collected from selected printing house are used for analysis and evaluation of environmental impacts. The components of all chemical used in the digital printing process are listed Table 5.2. Eco-Indicator 99 was then used to analyze and assessed the impacts.

- The major impacts on three categories (Human healthy, Ecosystem and Resource depletion) are shown on Figs 5.11-5.14
- The environmental impacts from impacts categories such as Carcinogens, Respiratory of organics, Respiratory of inorganics, Climate change, Radiation, ozone layer, Ecotoxicity, Acidification & Eutrophication, Land use and Minerals, are shown on Figs 5.15-5.18.
- A comparison of overall environmental impacts in each cases, is shown on Figs 5.19-5.20.

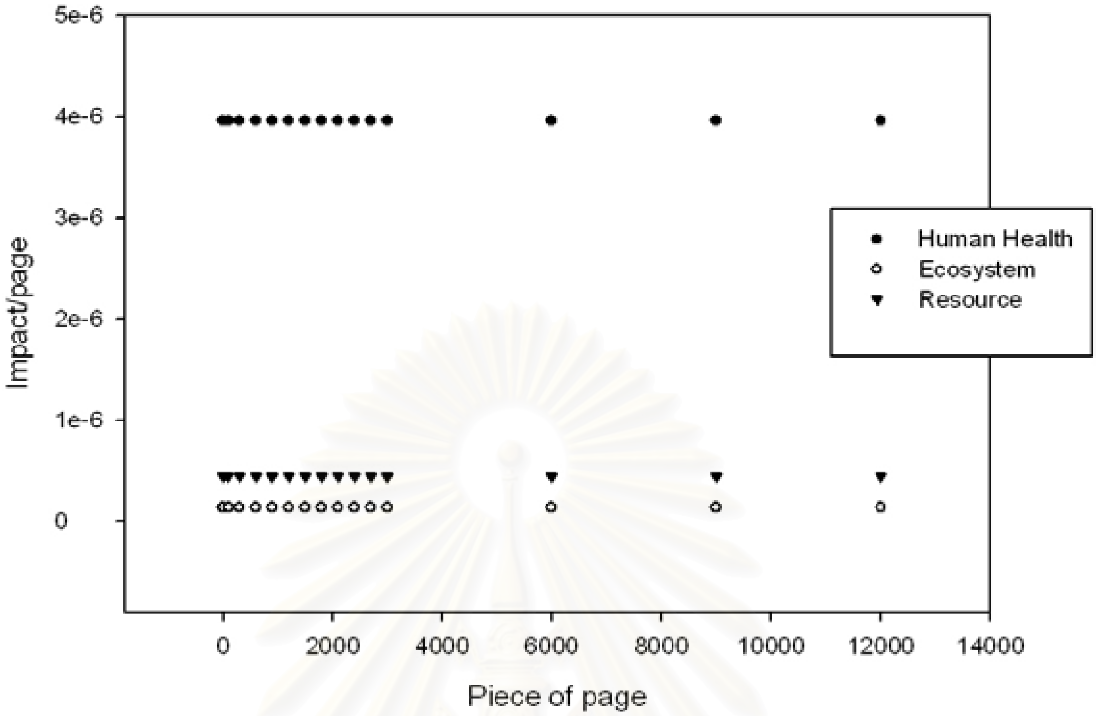

Figure 5.11: An environmental impact of Digital printing in terms of Human Healthy, Ecosystem and Resource depletion (Case 1)

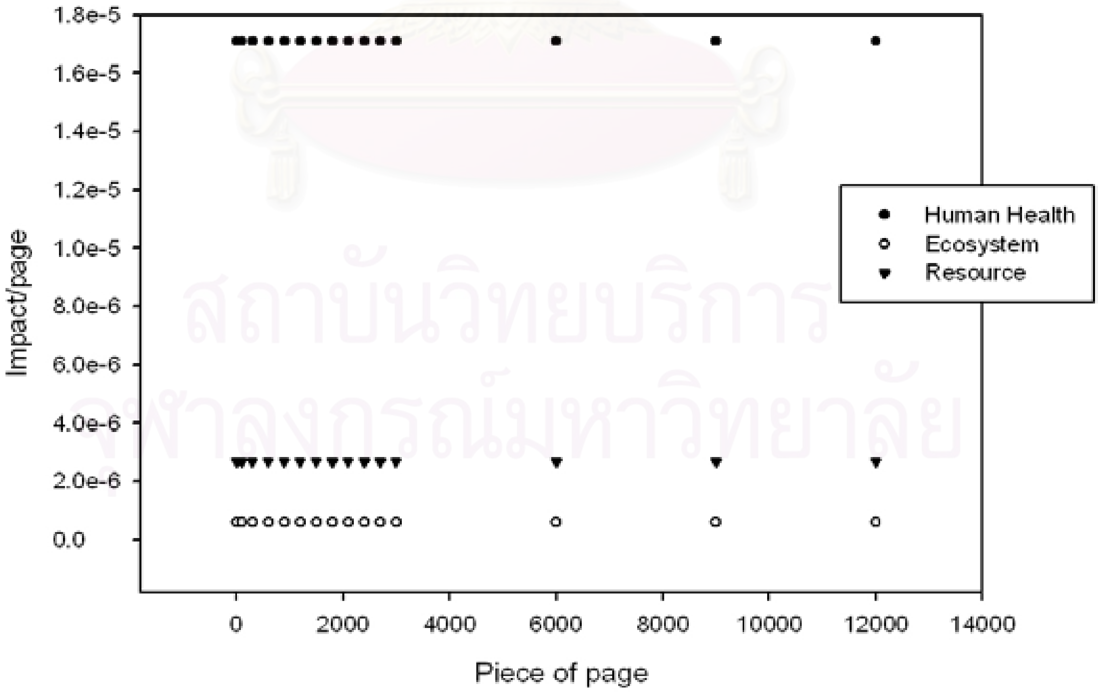

Figure 5.12: An environmental impact of Digital printing in terms of Human Healthy, Ecosystem and Resource depletion (Case 2)

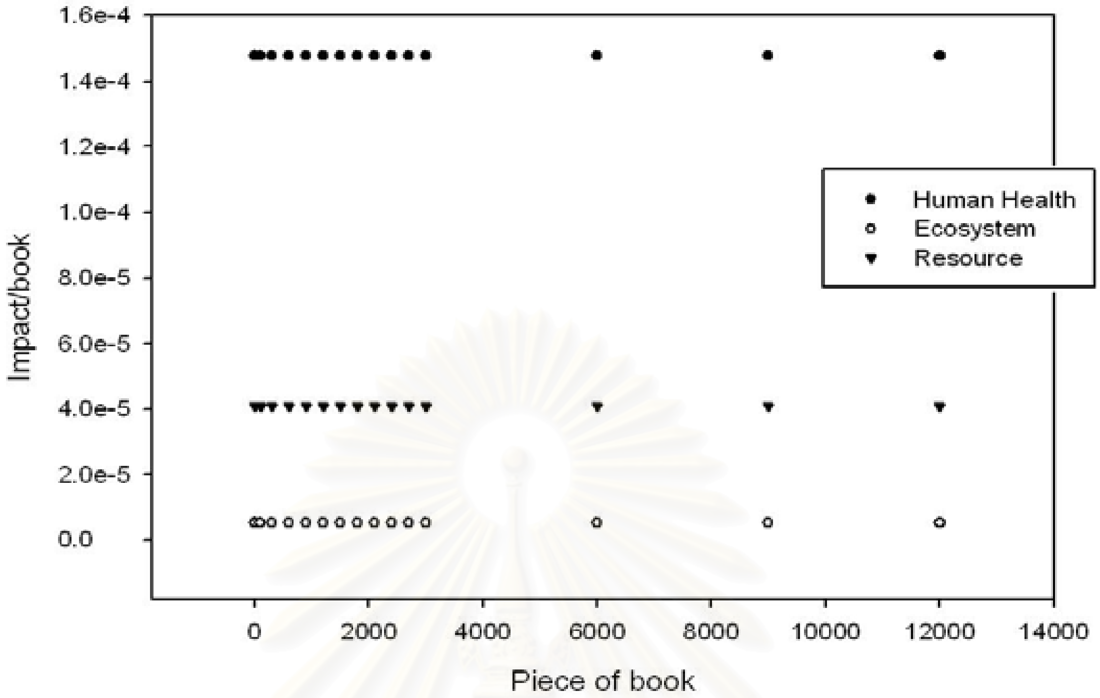

Figure 5.13: An environmental impact of Digital printing in terms of Human Healthy, Ecosystem and Resource depletion (Case 3)

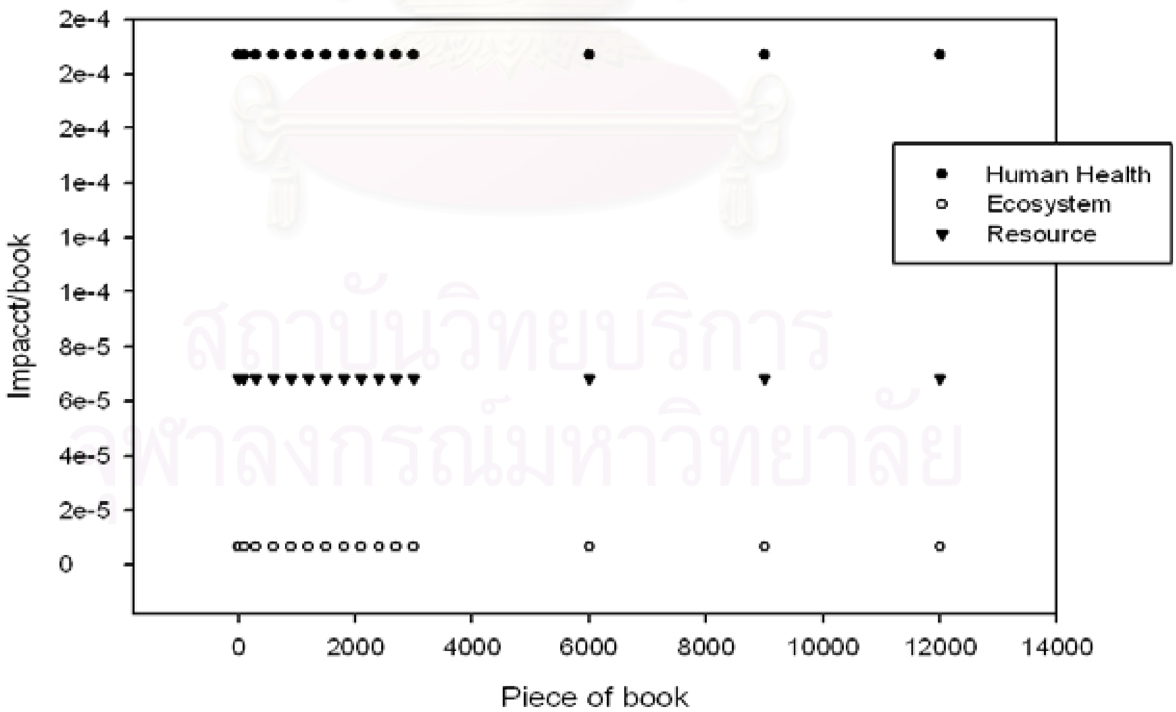

Figure 5.14: An environmental impact of Digital printing in terms of Human Healthy, Ecosystem and Resource depletion (Case 4)

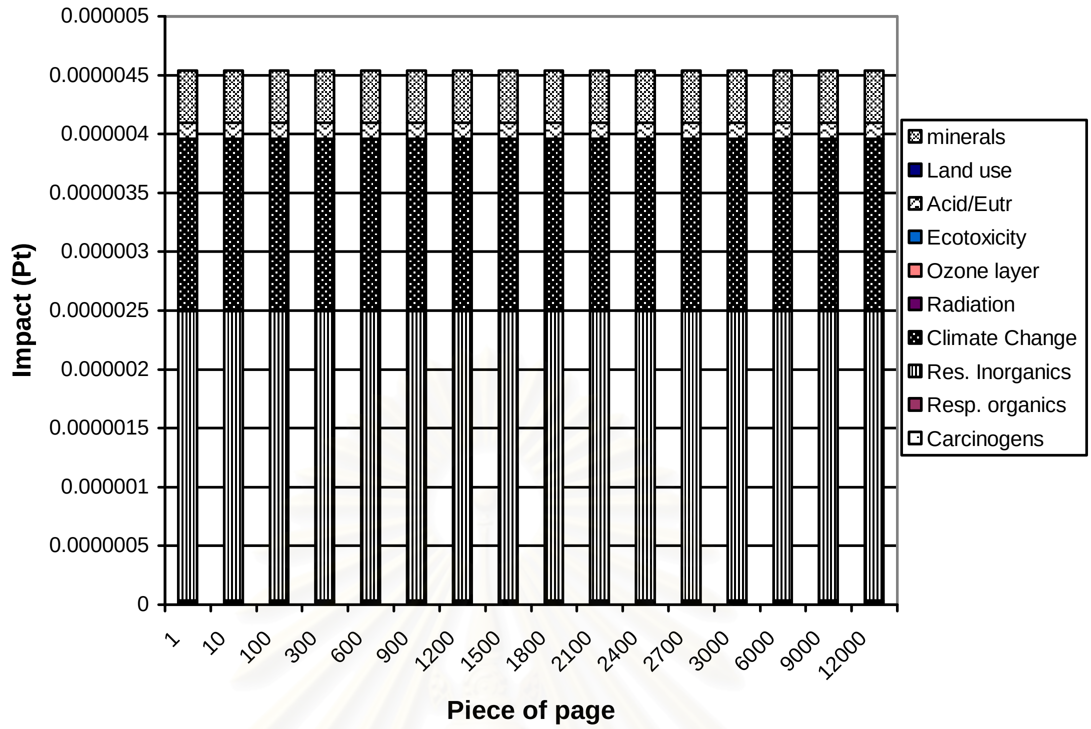

Figure 5.15: Minor environmental impact under Digital printing system (Case 1)

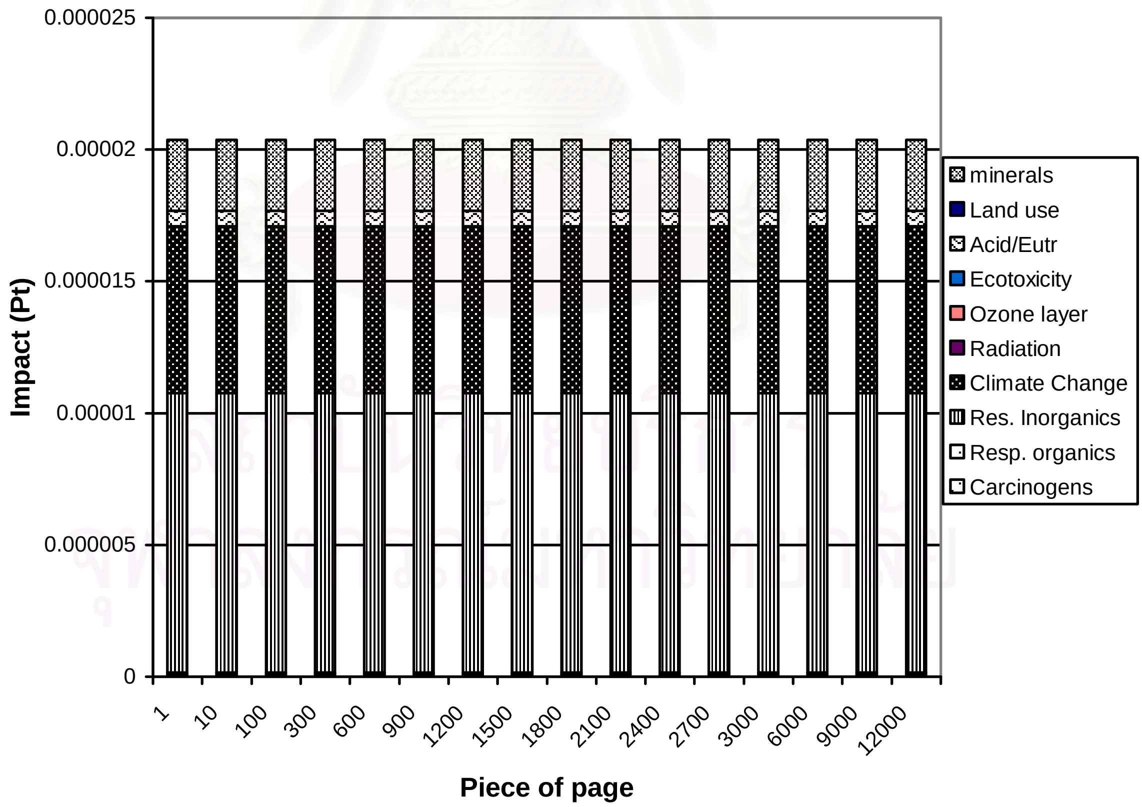

Figure 5.16: Minor environmental impact under Digital printing system (Case 2)

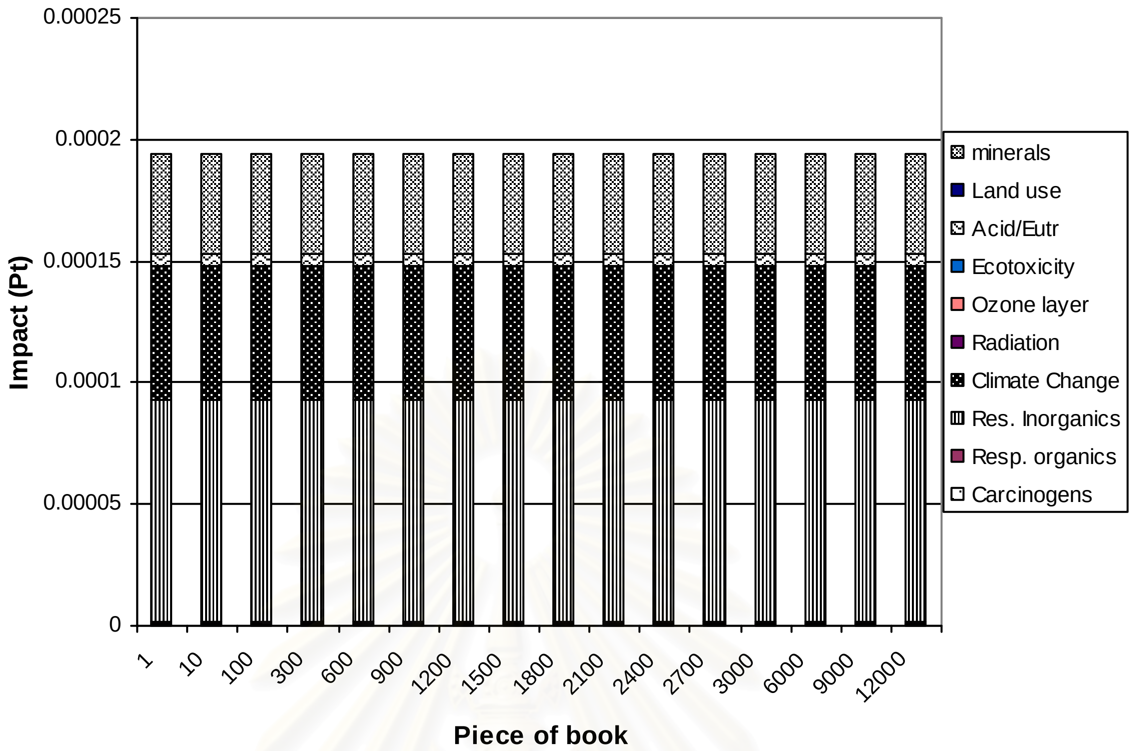

Figure 5.17: Minor environmental impact under Digital printing system (Case 3)

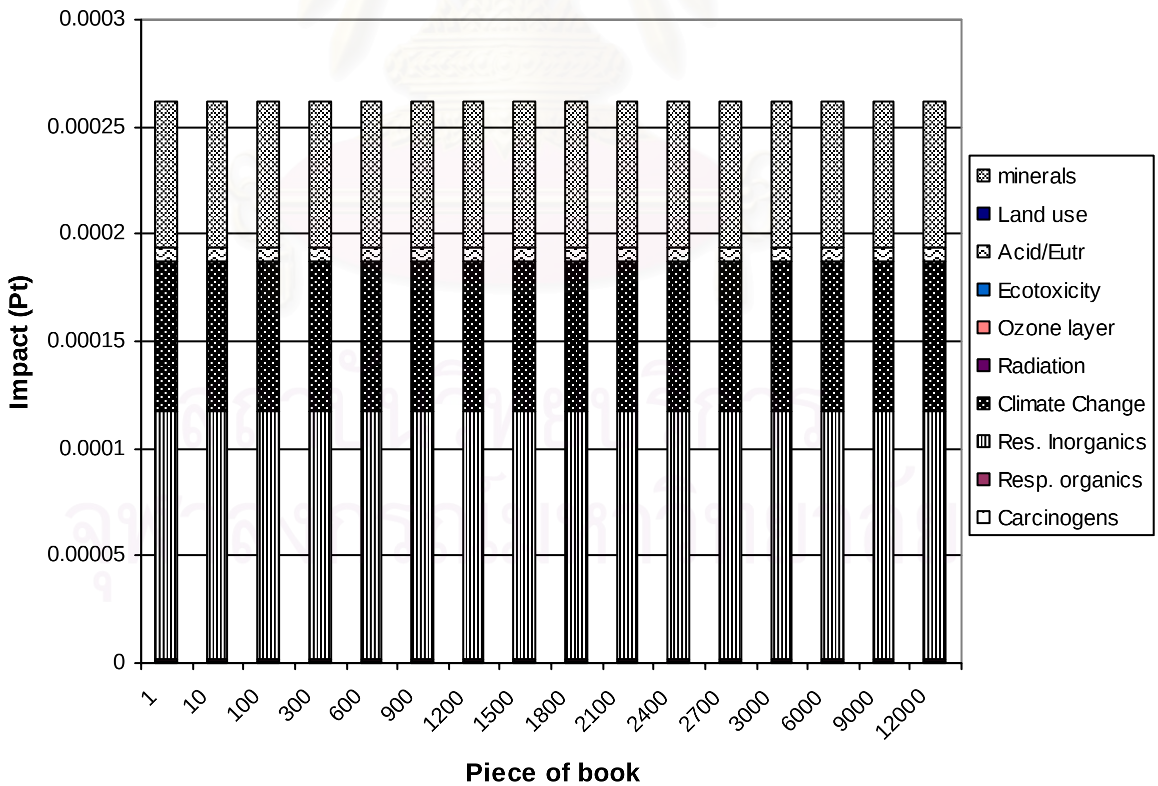

Figure 5.18: Minor environmental impact under Digital printing system (Case 4)

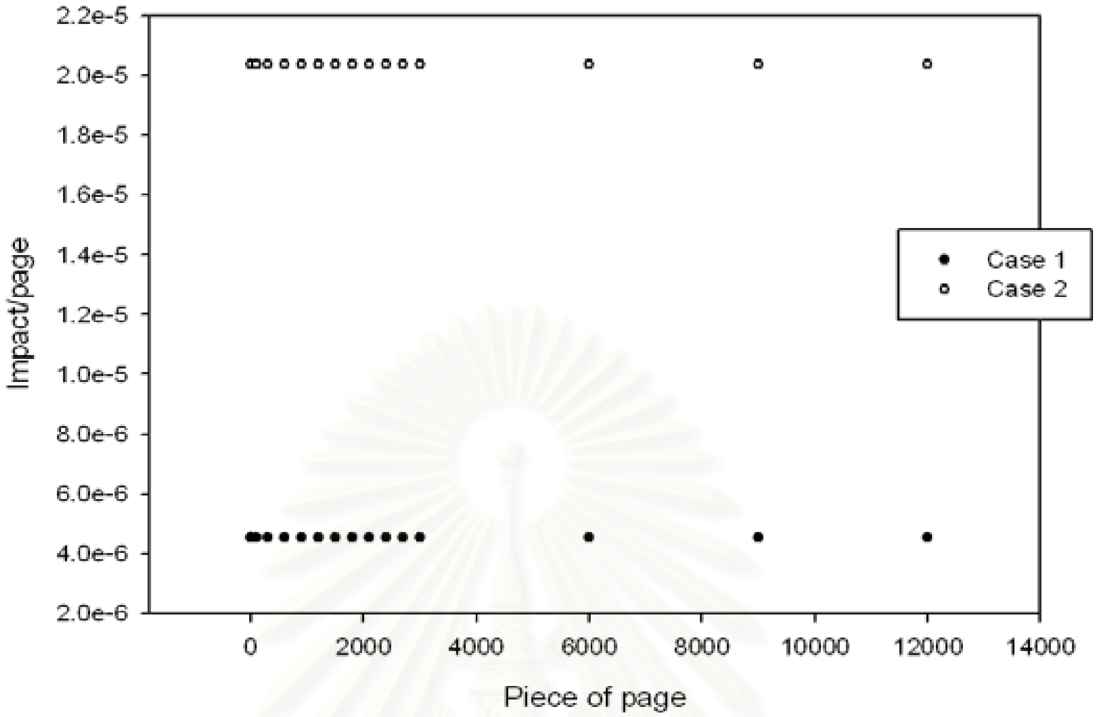

Figure 5.19: Caparison of environmental impact on Digital printing system among case 1 and case 2

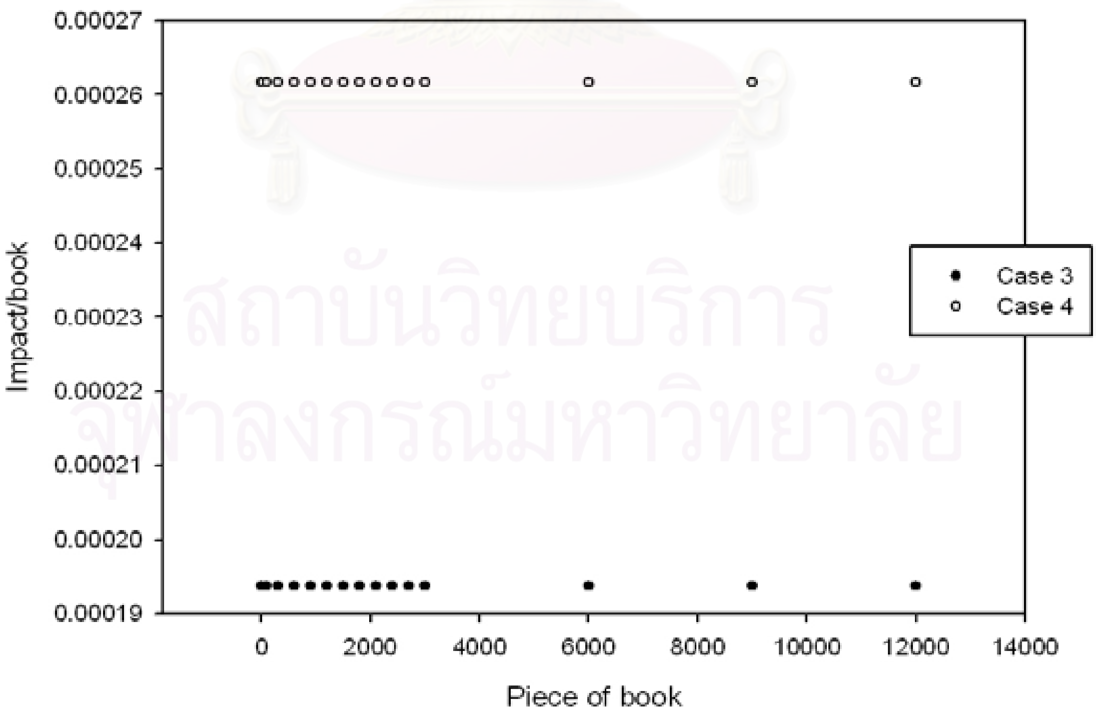

Figure 5.20: Caparison of environmental impact of Digital printing system among case 3 and case 4

5.2.1 Results in studying LCA under Digital printing system

Figure 5.11-5.14 represent major environmental impact of Digital printing system. In all cases, there is a similar tendency for the highest impact is on Human Health, Resource depletion and Ecosystem produce, respectively. This is caused of digital ink which is Toner. Toner is a powder which can disseminate in the air during printing process. Furthermore it also affect directly to Human Health.

Figure 5.15-5.18 represent minor environmental impact of Digital printing system. The highest impact is on Respiratory of inorganic and descending on Climate change, minerals, Acidification & Eutrophication and Carcinogens, respectively. The reason is Toner ink in printing process while there are only few impacts on Respiratory of organics, Land use, Radiation, Ozone layer and Ecotoxicity.

We compared the environmental impacts between one-color printing and 4-color printing system. Fig. 5.19 (1 printing paper) and Fig. 5.20 (a piece of printing book) show that printing case 2 has more environmental impacts than that of case 1,and printing case 4 (4-color printing) has more impacts than that of case 3. Because, 4-color printing (case 2 & 4) requires higher quantity of ink than in case of one-color printing (case 1 & 3).

5.3 Comparison of environmental impact between Offset printing system and Digital printing system

Figures 5.21-5.24 are shown a comparison of environmental impacts between Offset printing and Digital printing by using Eco-Indicator 99. Each case is classified by printing quantity as 100, 1000, 3000, 6000, 9000 and 12,000 piece of printing job and result in single score format.

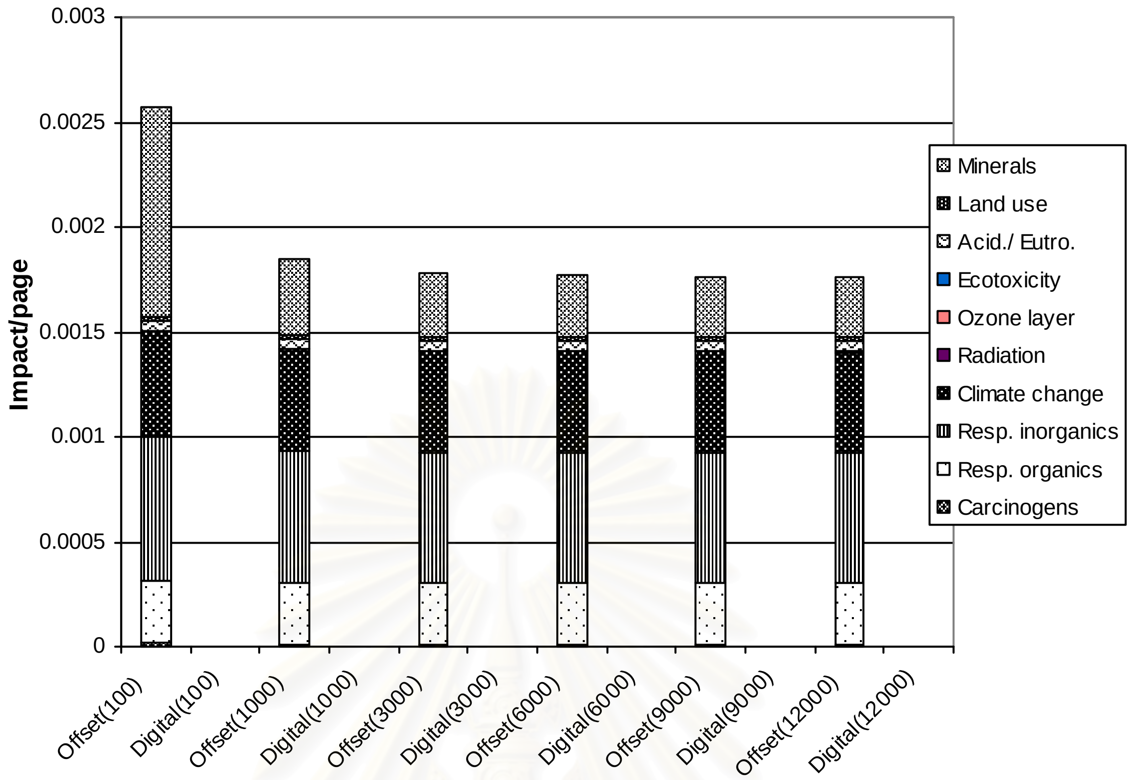

Figure 5.21: Caparison of environmental impact among 2 systems in case 1

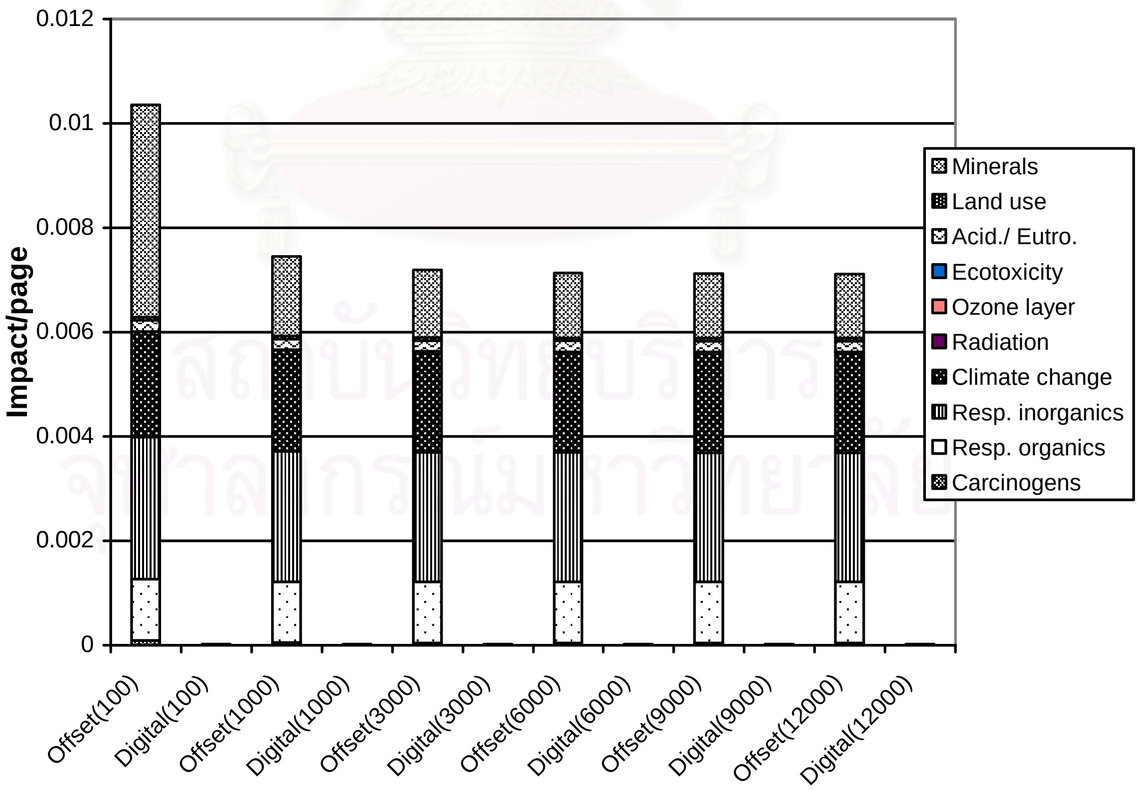

Figure 5.22: Caparison of environmental impact among 2 systems in case 2

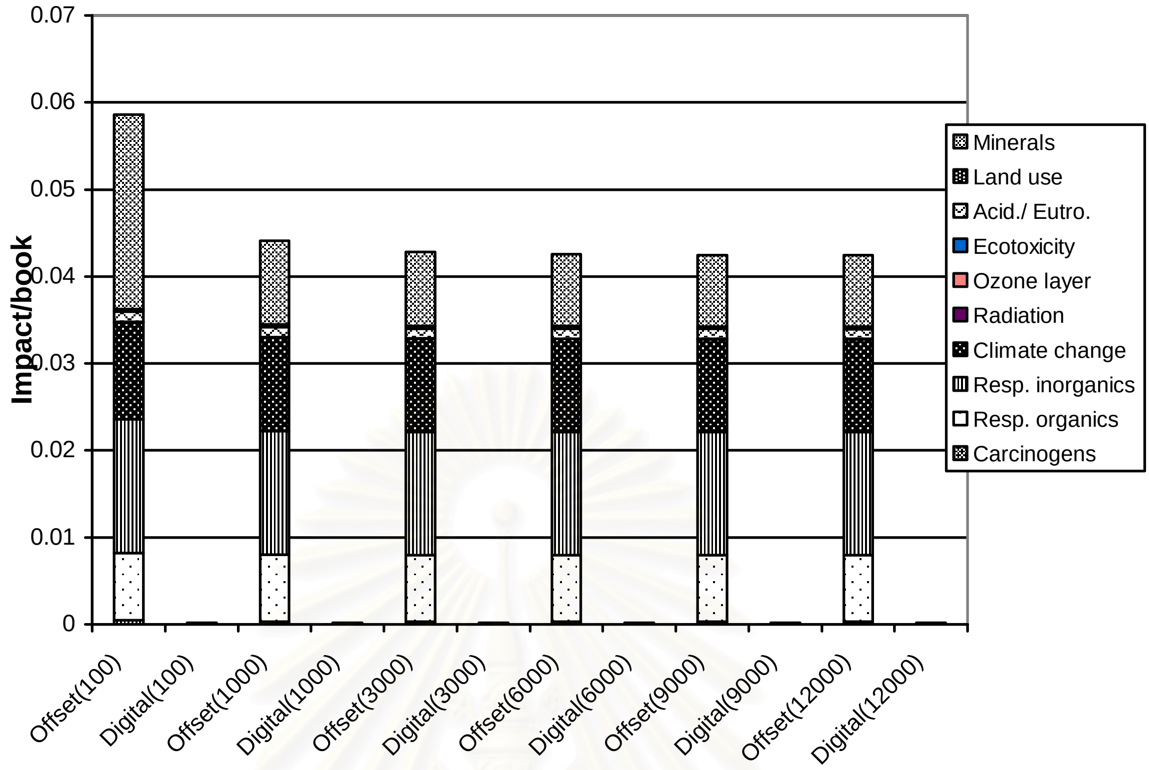

Figure 5.23: Caparison of environmental impact among 2 systems in case 3

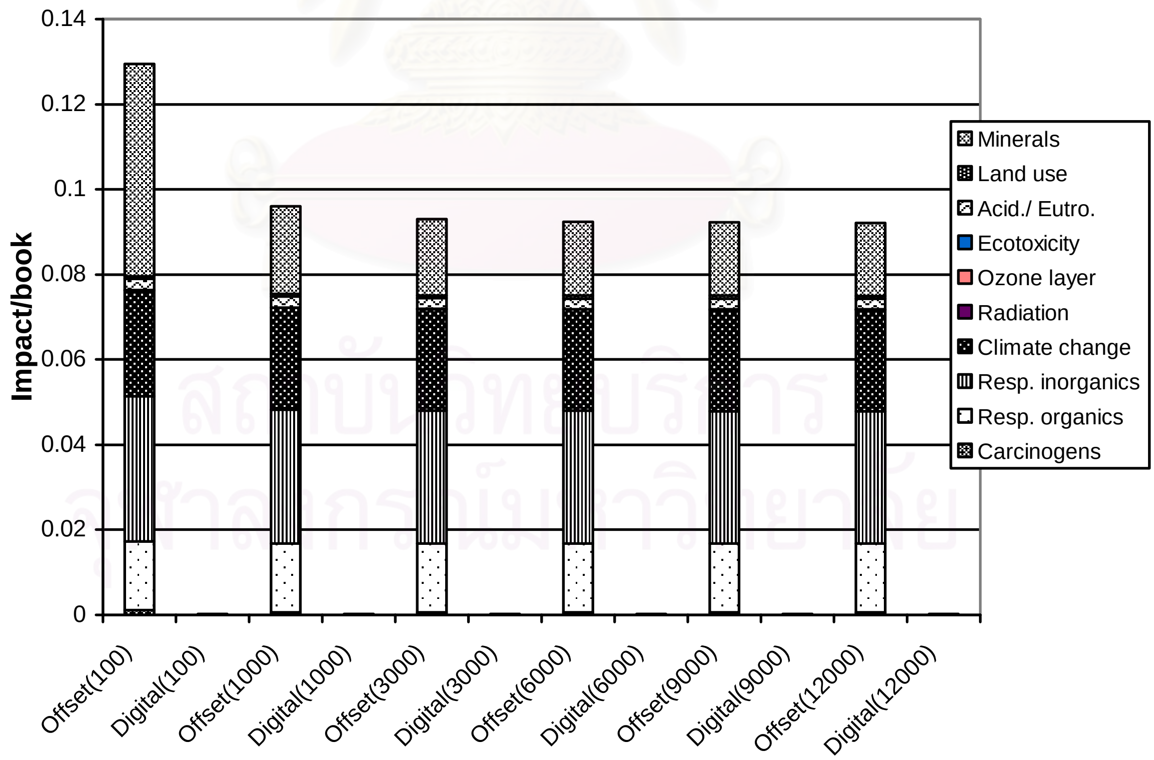

Figure 5.24: Caparison of environmental impact among 2 systems in case 4

5.3.1 Result of environmental impact between Digital printing system and Offset printing system

Figures 5.21-5.24 show a comparison on minor environmental impacts among 2 types of printing system. In all case, there is a similar tendency for the environmental impact and can be described in next paragraph.

Offset printing system will create an environmental impact in all categoies because of the complexity in printing process and the consumption of various chemical components. In contrast, digital printing system uses only Toner ink and affects in a few impacts of Human Health. Offset printing system results in variety of impact categories as following:

- Environmental impacts in Respiratory of inorganic and Respiratory of organics are created from fountain solution ink and cleaner in printing process,
- Environmental impacts in Climate change, Acidification & Eutrophication are created from Fixer and Developer solution in Image setter and Plate making and,
- An environmental impact in mineral is created from Plate making process.

5.4 The way to reduce environmental impact under Offset printing system

Offset printing system has high levels of environmental impacts in almost all categories. This is an important issue leading us to find out the solution to reduce the impacts by the replacement “Isopropanol” chemical material by “Surfactant” in Fountain solution and replacement “Alchohol based” by “Water based” in printing system. Both of them can improve the environmental impact by reducing VOCs.

The printing process can create a high level of environmental impacts. The replacement of chemical material is one solution which we give an attention. In this experiment, we replace Benzene by vegetable oil in order to reduce VOCs and show the results as following:

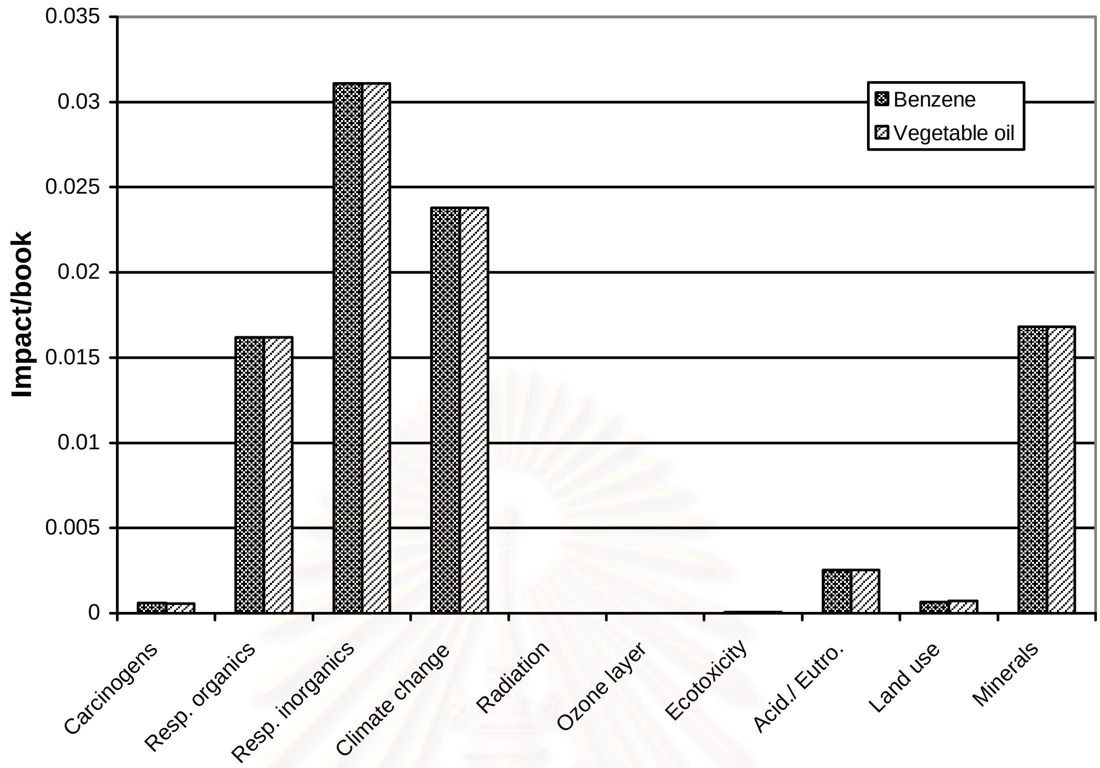

Figure 5.25: Environmental impact between Benzene and Vegetable oil under Offset printing system (Case 4).

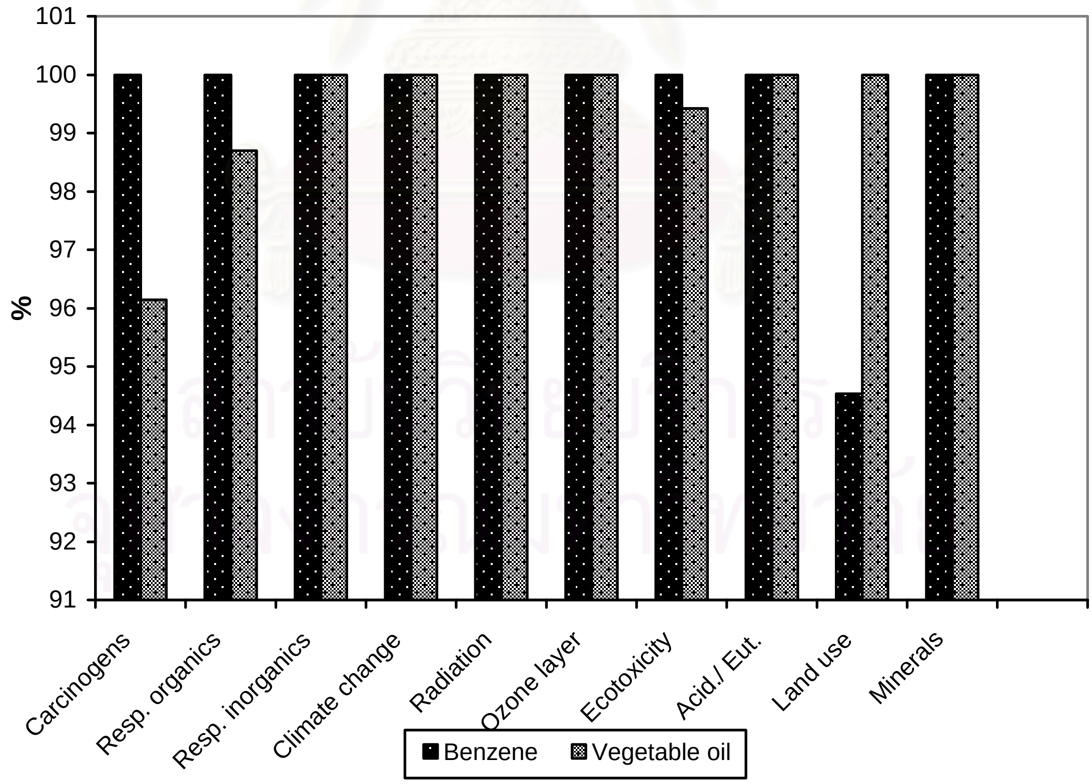

Figure 5.26: Compare an Environmental impact changes between Benzene and Vegetable oil under Offset printing system (Case 4) by percentage.

5.4.1 The result of environmental impact by using vegetable oil

Figure 5.25 shows the environmental impacts by replacement Benzene with vegetable oil. There are similar impacts in term of Carcinogens, Respiratory of organics, and Respiratory of inorganics, Climate change, Acidification/Eutrophication, Land use and Mineral. While Fig. 5.26 shows the changes of impact by decreasing Carcinogens 3.86%, Respiratory of organics 13%, Ecotoxicity 0.58% and increasing of Land use by 5.47%.

CHAPTER VI

ECONOMIC OF OFFSET AND DIGITAL PRINTING SYSTEMS

Nowadays Offset printing and Digital printing are the most favorite systems in printing service industry. Both of them have more advantages and disadvantages in different ways; however they are also an effective system in printing service. In term of time constraint, Offset printing requires higher production time than that of Digital printing. Because, Offset printing requires Film and Plate processing while Digital printing can be directly transfer all data through computer and finish in one step. So we can conclude that Digital printing system is appropriate for urgency printing job.

In addition, we also studied the cost of each printing system in order to find out the best choice for consumer decision making. We investigated the system in 4 case studies as following:

Case 1: a piece of black & white printing paper

Case 2: two pages of 4-color printing

Case 3: one piece of book, black & white printing

Case 4: one piece of book, 4-color printing

6.1 Equilibrium cost analysis

We studied the cost and expenditures in each printing system and resulting in understanding the relationship between variables cost and printing outputs.

If N = quantity in production

C = Cost

$C \alpha N$

$C = KN$

It is very necessary in separating fixed cost and variable cost. The data below will be represented the fixed cost and variable cost of each printing system.

Fixed cost and Variable cost

Fixed cost is an expenditure which is not changed on different level of production. This type of cost can be added to the cost of asset and inventory values. For example; equipment & machine cost and Building site. Variable cost is the cost which is changed on the increasing or decreasing production quantity such as cost of raw materials.

6.2 Comparison of Equilibrium cost analysis between Offset and Digital printing

Table 6.1: Type of cost between Offset and Digital printing system

Offset printing		Digital printing	
Fixed cost	**Variable cost**	**Fixed cost**	**Variable cost**
Film	Ink	-	Ink
Plate	Wages		Wages
Chemical solution	Paper		Paper
Wages	Booking		Booking
Depreciation rate	Depreciation rate		Depreciation rate
Color approve			

As regards on table 6.1, we have to compare the marginal cost on each printing system. The case studying will be separated on 4 criteria as following:

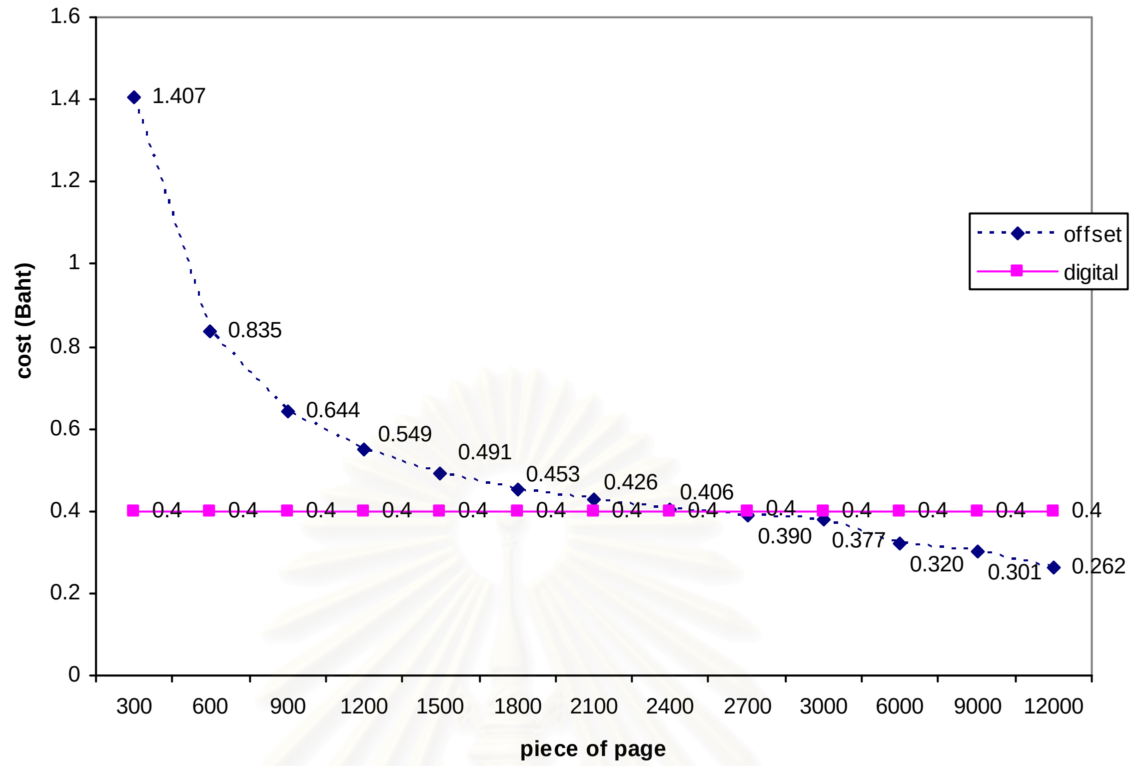

Figure 6.1: Price per piece of page between Offset and Digital printing (case 1)

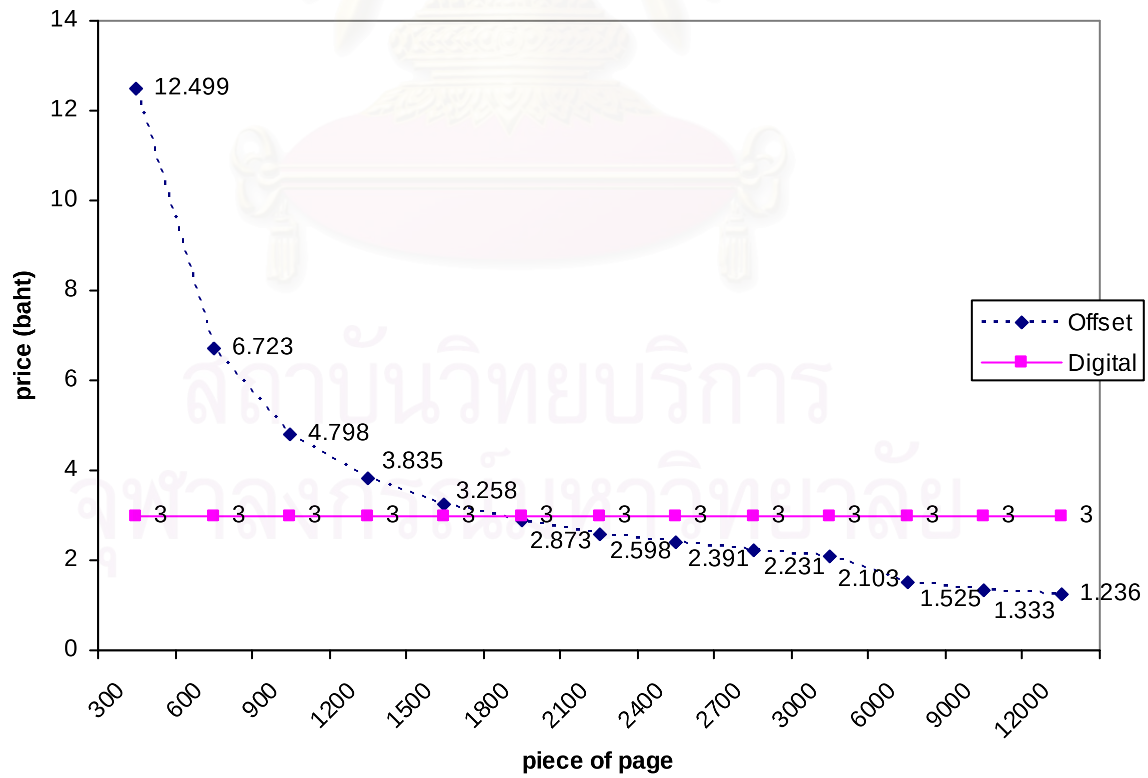

Figure 6.2: Price per piece of page between Offset and Digital printing (Case 2)

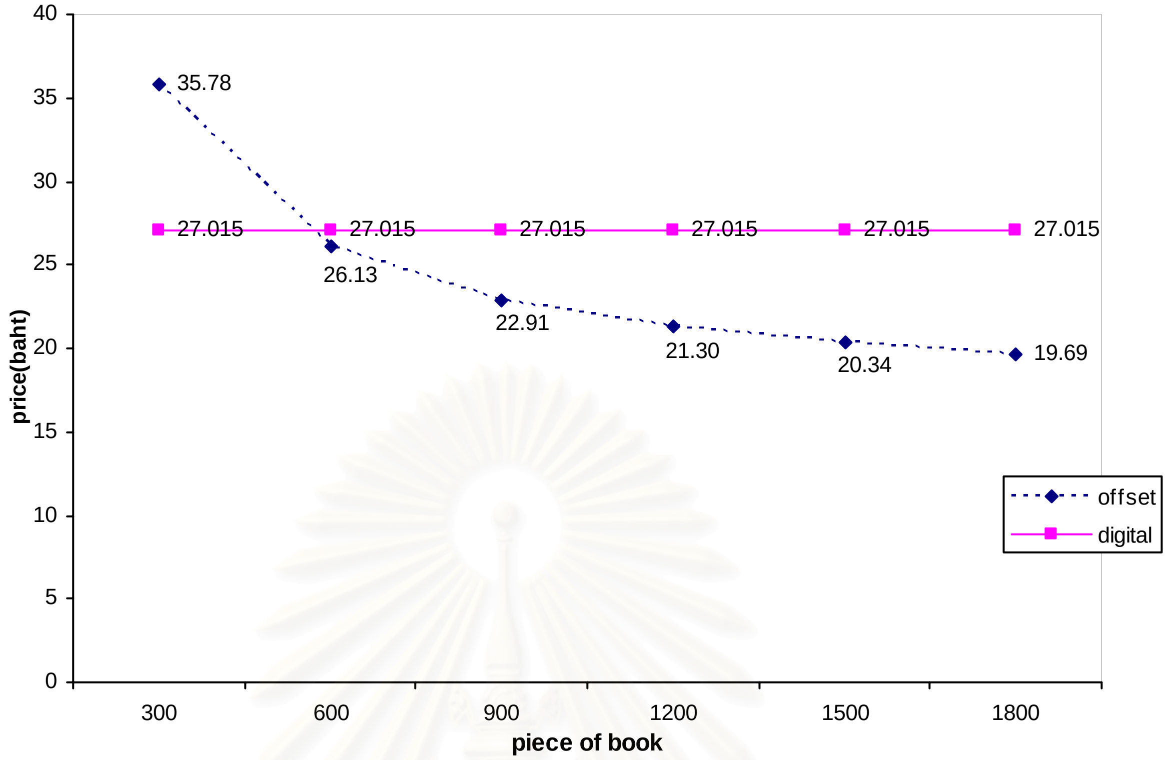

Figure 6.3: Price per piece of book between Offset and Digital printing (Case 3)

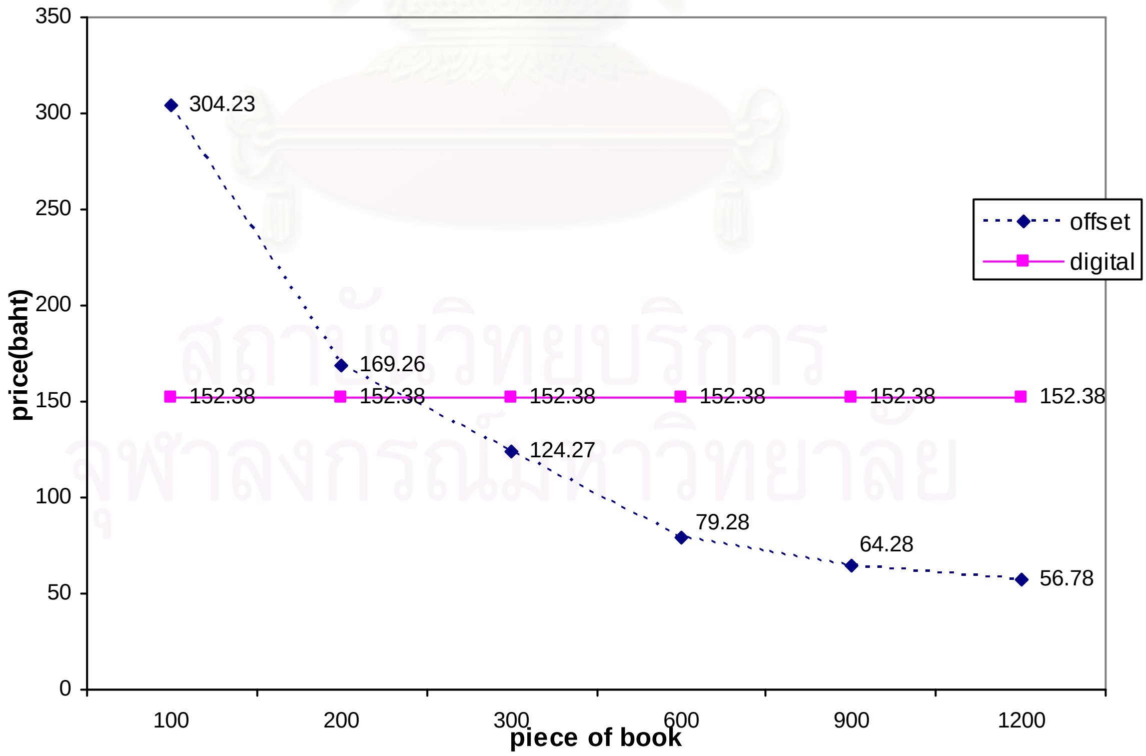

Figure 6.4: Price per piece of book between Offset and Digital printing (Case 4)

6.3 Summarized of equilibrium price between Offset and Digital printing system

According to case 1 (Figure 6.1) a piece of paper (black & white printing job), the result shows an equilibrium quantity at 2,400 pieces of printing paper. It means that printing job at 1-2,399 piece(s) of paper; Digital printing will be cheaper than Offset printing. However, if printing job is higher than 2,401 pieces of paper, Offset printing will be cheaper than Digital printing.

According to case 2 (Figure 6.2) a piece of paper (4-color printing job), the result shows the equilibrium quantity at 1,685 pieces of paper. It means of printing job at 1-1,684 piece(s) of paper, Digital printing will be cheaper than Offset printing. In contrast, if printing job is higher than 1,686 pieces of book, Offset printing will be cheaper than Digital printing.

According to case 3 (Figure 6.3) printing job of a 76-pages book (Black $ white printing), the result shows an equilibrium quantity at 550 pieces of book. It means of printing job at 1-549 piece(s) of book, Digital printing will be cheaper than Offset printing. In contrast, if printing job is higher than 551 pieces of paper, Offset printing will be cheaper than Digital printing.

Finally on case 4 (Figure 6.4) printing job of a 132-pages book (4-color printing), the result shows the equilibrium quantity at 229 pieces of book. It means of printing job at 1-228 piece(s) of book, Digital printing will be cheaper than Offset printing. In contrast, if printing job is higher than 230 pieces of book, Offset printing will be cheaper than Digital printing.

CHAPTER VII

CONCLUSION AND RECOMENDATIONS

7.1 Conclusion

In this research, we studied the environmental impact on Offset printing system and Digital printing system. The research is studied by LCA method and used Eco-Indicator 99 in SimaPro6.0 software. We set the case study and collect sample data by 4 categories as one black & white printing paper, 4-color printing paper, black & white printing book and 4-color printing book.

As of the results of studying, we can conclude that **Offset printing system** can affect the high impact on Minerals, Respiratory of inorganic, Climate change, Carcinogens and Respiratory of organics respectively. Furthermore, an environmental impact on each printing output will decrease in every increased of printing output. In conversely, **Digital printing system** can affect the high impact on Respiratory inorganic, Climate change, Minerals, Acidification & Eutrophication and Carcinogens respectively. Furthermore, an environmental impact will be constantly in every level of printing output. After that we compare environmental impacts of both systems. The results show that Offset printing system can affect higher impact than Digital printing system in all aspects. This is caused of higher chemical requirement in Offset printing system while Digital printing system use only Toner ink in printing process.

As on result in high impact level of Offset printing system, we have to study the way to decrease an environmental impact. According to this research, we focus on replacement Benzene by Vegetable oil in the chemical components and find out the environmental impact on LCA processing by using Eco-Indicator 99 in SimaPro6.0 soft ware. As on the experimental result, the impact will decrease only a few in term of Carcinogens, Respiratory of organics, Ecotoxicity while will increase the impact in term of Land use.

In next step, we study the cost of production among two types of printing system. As on the result, the cost of Digital printing system will be cheaper than Offset printing system if printing output is allocated in low level. But if the printing output is allocated in high level, Offset printing system will be cheaper than Digital printing system. Furthermore the production cost will be decreased in every increased of printing output.

According to the environmental impact and cost of production studied, it is benefits to entrepreneurs in selecting appropriate printing system to control an environmental impact. Moreover it also benefit in term of cost advantage and type of printing system Furthermore it is benefits to any people in selecting an appropriate printing system to their printing job.

7.2 Recommendations

7.2.1: Nowadays, there are many research proposals in topic of “Decreasing an environmental impact on Offset printing system” in many ways such as changing the chemical components, changing printing system, changing chemical in cleaner and so on. All of proposal should study by LCA method in order to highest environmental impact reduction.

7.2.2: the printing quality is one necessary factor which should be studied in order to compare the printing quality of Offset and Digital printing system.

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APPENDICES

APPENDIX A

SimaPro6.0

SimaPro6.0 is the software which aims to evaluate environment impact such as an analysis under ISO requirements. Furthermore software can be used to compare the result of specific target data and resulting in database, comparison result in table and graph. The result is more flexible for additional data and used more length of time in data development. This program is most appropriate for Social engineer and engineering designer. At present, there are other LCA programs which are developed as same as SimaPro6.0. However SimaPro6.0 has more advantages than other programs as price and product acceptance from users. These advantages can be proved from the volume sales of SimaPro6.0. So we can realize that SimaPro6.0 will be appropriated for this research project and evaluate the environment impact on cycle of MWNTs.

Environment Impact Analysis

According to environment impact analysis, the author has to divide the topic studied as following:

Characterization criteria

This criterion will be represented type of environment impact in term of an indicator multiply by Characterization factor. The result will be changed from weight to environment indicator and summarized all data as of equation below:

$$EP_j = \sum (Q \times EF_{ij})$$

EP_j (Environmental impact potential) is an efficiency of environment impact for any impact j (kg substance equivalent)

Q (Quantity of substance) is volume of chemical component that is released (kg substance j)

EF_{ij} (Equivalency factor) is comparative value of component i that effect to environment j (kg substance equivalent / kg substance j)

Normalization

This step is represented the size of impact on product or service

$$NP_{j(product)} = EP_j /(T \times ER_j)$$

$NP_{j(product)}$ (Normalized environment impact potential) is normality impact value on environment j of product

T (Lifetime of product) is useful life of product (year)

ER_j (Normalization Reference) is reference value on environment impact j which is happened from one person per year. (kg substance equivalent / person / year)

Weighting

This step is represented the important of 3 environment as Human healthy, environment cycle and natural resource and resulting in above 3 factors to be a one data.

$$WP_j = WF_j \times NP_j$$

WP_j (Weighted environmental impact potential) is efficiency value on environment impact j after weighting necessary value (person for target year; Pt.)

WF_j (Weighting factor) is an expectation of necessary weight proportion on environment impact j in each year

Eco-indicator 99

Nowadays there are many methods in calculation environment impact such as Ecoscarcity method and Environmental theme method developed by Baumann (1994), EdIP (Environmental Design of Industrial Products) method developed by Wenzel (1997), EPS method Centre for Environmental Assessment of Products & Material Systems and Eco-indicator 99 developed by Pre' Consultants (1999). Eco-indicator 99 method is most favorable and result in good reference data of product's environment. Moreover it also used for resource management with the aim to develop an environment.

Environment impact's evaluation process of Eco-indicator 99

1. Material, energy and garbage will be separated by type of 9 impacts.
2. Type of 9 environment impacts will be separated on 3 target groups
3. Weighting process will be concluded on one result

Target group and type of environment impact will be represented as following:

"Human Healthy" will be consisted of Carcinogenic, Respiration of organic substance and inorganic substance, Climate change and Ozone depletion.

"Ecosystem" will be consisted of Acidification & Eutrophication and Ecotoxicity.

"Resource depletion" will be consisted of Mineral and Fossil fuels usage rate

APPENDIX B

Economic of Offset and Digital printing systems

In additional criteria studied, the author also studied about the cost of each printing system with the aim of finding out the best choice for consumer decision making. According criteria, it will be represented through studying in 4 cased studies as following:

Case 1: one page of black & white

Case 2: 2 pages of 4-color

Case 3: one piece of book, black & white

Case 4: one piece of book, 4-color

Table 1: Presentation for calculation of cased 1

Fix costs		
Type	**Explanation**	**Price (Baht)**
Plate	Cover cutting 4 pieces at totally 1 color of piece	85
	Chemical (5% of plate)	4.25
	Wages 10 min. (50 B./hr.)	6.25
Film	Size A4(1 color 1 sheet)	100
	Chemical at 2% film (1 piece)	2
	Wages 10 min. (300 B./hr.)	50
	Depreciation rate (Film & Plate) 20 min. (287 B/hr.)	96
Color Proved	-	-
		343.5
Variable Costs (5,000 sheets)		
Type	**Explanation**	**Price (Baht)**
Ink	Black color	20
Printing	Wages 2 hr.	130
	Depreciation rate 2 hr. (115 /hr.)	230
	Chemical 1% of printing cost	6
Paper supplies	Cover 70 gram 31x43	912
	Wages of Cutting 10 min.	14
		1,312
	Average variable costs per piece	0.2624

Table 2: Presentation for calculation of cased 2

Fix costs		
Type	**Explanation**	**Price (Baht)**
Plate	Cover cutting 4 pieces at totally (4 color/ 4 plate)	400
	Chemical (5% of 4 plates)	20
	Wages 10 min.	25
Film	Size A4(4 colors 4 sheets)	1,720
	Chemical at 2% film (4 pieces)	34.5
	Wages (Art 1 hr. Lay 30 min.)	279
	Depreciation rate (Film & Plate) 1 hr. (287 B/hr.)	287
Color Proved		700
		3,465.5
Variable Costs (20,000 sheets)		
Type	**Explanation**	**Price (Baht)**
Ink	Yellow	931
	Cyan, Magenta, Black	155
Printing	Wages 5.30 hr.	1,410
	Depreciation rate 5.30 hr. (444 /hr.)	2,442
	Chemical 1% of printing cost	122
Paper supplies	Cover 120 gram 24x35	13,800
	Wages of Cutting 1 hr.	90
		18,950
	Average variable costs per piece	0.9475

Table 3: Presentation for calculation of cased 3

Fix costs		
Type	**Explanation**	**Price (Baht)**
Plate	Cover cutting 4 pieces at totally 20 piece of paper	2,000
	Chemical (5% of 20 plates)	100
	Wages 2 hr. (50 B./hr.)	100
Film	Size A4 (20 sheets)	2,000
	Chemical at 2% film (46 pieces)	40
	Wages 1.40 hr. (300 B/hr.)	500
	Depreciation rate (Film & Plate) 3.40 hr. (287 B/hr.)	1,052
Color Proved	-	-
		5,792
Variable Costs (1,000 books)		
Type	**Explanation**	**Price (Baht)**
Ink	Cover 500 ml. (343 B/1000 ml.)	172
	Cover-in black 1000 ml.	280
Printing	Printing 7.30 hr.(115 B/hr)	863
	Depreciation rate 7.30 hr. (444 /hr.)	3,330
	Chemical 1% of printing cost	280
Paper supplies	Cover 260 gram 25x36	1,644
	Cover-in 80 gram 24x35	8,255
	Rolling and rearranged	152
	Edging and cutting (1.50 Baht each)	1,500
		16,476
	Average variable costs per piece	16.476

Table 4: Presentation for calculation of cased 4

Fix costs		
Type	**Explanation**	**Price (Baht)**
Plate	Cover cutting 4 pieces at totally 46 piece of paper	4,600
	Chemical (5% of 46 plates)	230
	Wages 4.30 hr. (50 B./hr.)	225
Film	Size A4(1 color 24 sheets & 4 colors 22 sheets)	11,860
	Chemical at 2% film (46 pieces)	237
	Wages 3.50 hr. (300 B. /hr.)	1,150
	Depreciation rate (Film & Plate) 8.20 hr. (287 B/hr.)	2,392
Color Proved	9 x 700 B.	6,300
		26,994

Variable Costs (17,000 books)		
Type	**Explanation**	**Price (Baht)**
Ink	Cover 3500 ml. (343 B/1000 ml.)	1,200.5
	Cover-in blue 9000 ml. (294 B. /1000 ml.)	2,646
	4-color 20000 ml. (343 B/1000 ml.)	6,860
Printing	Printing 192 hr.(115 B/hr)	22,080
	Depreciation rate 192 hr. (444 /hr.)	85,248
	Chemical 1% of printing cost	7,953.93
Paper supplies	Cover 260 gram 25x36 (2990 baht)	30,498
	Cover-in 105 gram 24x35 (1200 baht)	246,336
	Paper 105 gram 24x35	142,800
	Rolling and rearranged	3,264
	Edging and cutting (2 Baht each)	34,000
		582,886.43
	Average variable costs per piece	34.287

VITA

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