SUSTAINABILITY IN THE PRINT AND PACKAGING INDUSTRY

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In the printing and packaging industry, sustainability is defined as manufacture and practices that reflect responsibility for the environment and resources to meet the needs and expectations of future generations. In this article, raw material management, cellulose resources, industrial forests, ecological and renewable alternative fiber resources were examined in the framework of the sustainability of the printing and packaging industry. The recycling of printed materials and packaging and the effects of paper-ink types and product design in this recycling have been discussed. The effect of separation and processing at the source on the efficiency of paper recycling, economy and ecology was emphasized. The greenhouse gas emissions of solvents used in inks and cleaners, the impact on climate change, water footprint and carbon footprint issues were examined. Suggestions have been made on environmental sustainability in the printing industry, what needs to be done for a competitive production, successful optimization, minimization of waste, use of existing possibilities, recycling and evaluation of alternatives and use of clean energy.

Keywords: sustainability, green printing, packaging, environmental sustainability, alternative fibers, paper recycling, carbon footprint

INTRODUCTION

The concepts that express sustainability in the printing industry are recycling, deinking, renewability, compostability, biodegradability, carbon footprint, water footprint, environment, and global economy. For the printing industry, sustainability has gained a significant amount of attention due to the demands of customers, environmental groups, investment companies, government agencies and consumers.[1] For this reason, green initiatives and sustainable production practices have gained momentum in production processes. Optimized applications keep the environmental awareness alive in the printing industry and create a sustainable cycle that involves the consumer as well as the production.

Sustainability in the printing industry is a global and essentially economic problem that requires huge resources to meet and affects the circular economy (Fig. 1).[2] With the increasing environmental awareness, the importance of reducing the use of natural resources is increasing day by day.

The paper industry and academic scientists have been paying increased attention to paper recycling and the search for alternative fiber resources.[3] Numerous studies have emerged in recent years on the use of non-wood materials, including alternative fibers, agricultural wastes and vegetables, as a source for cellulosic pulp production.[4-12] Many countries without forests have to use agricultural residues as raw materials for paper and cardboard production. However, in countries rich in forests, there is a trend to use agricultural residues – if available – in order to reduce deforestation.[4]

There are many alternatives for sustainability, from using less material in packaging, to using renewable raw materials, and to production regulations to reduce emissions of printing chemicals. Manufacturers can reduce dependency on primary materials for sustainability, prefer recycled substrates, and use renewable energy sources in their printing processes. With more innovative business models, they can reduce their costs and provide new sources of income. Thus, they can increase their competitive advantages.[13]

Traditionally performed complex business processes, production processes, and inefficient use of employee skills also increase resource waste. Efficient use of renewable resources with simplified business processes makes a sustainable working environment possible. The biggest challenge in implementation is improving the

relationship between business, practical and sustainable priorities.

Environmental sustainability focuses on the quality and quantity of the natural environment, which provides the necessary life support for the survival of human life and the prior condition for the existence of an economy. This quality and quantity are called natural capital by neoclassical and environmental scientific economics.[14]

The enforcement of environmental management policy is crucial for both office and manufacturing staff. For this reason, the printing industry has to take managerial decisions in order to maintain a developed relationship between man and the environment. Especially in the field of professional practice such as printing processes, the selection of the right material, the control of waste generation and disposal procedures are extremely important.[15]

Printing companies, just like other companies, give more importance to the need to be environmentally sustainable. The technology and material that a printing house chooses for the product it will produce will help determine how environmentally conscious it will be. In particular, inks cause a lot of controversy in terms of the overall sustainability of the print.

With regard to ink, energy use, waste disposal and toxic reductions in the manufacturing process must be considered. In addition, the supply of the raw materials that make up the inks, the environmental impact of these materials, the effects they may have on the production working environment, the ability to remove ink from printed materials and packaging for recycling are also important for sustainability.

Optimization of the printing value and process chain (Fig. 2)[16] provide environmental, economic and business benefits. End users, direct customers, printers and suppliers should together make the process value chain more efficient to improve its environmental efficiency. For this purpose, low environmental impact, recycling, reducing waste and energy efficiency studies should be carried out in design, determination of raw materials, production and logistics processes.

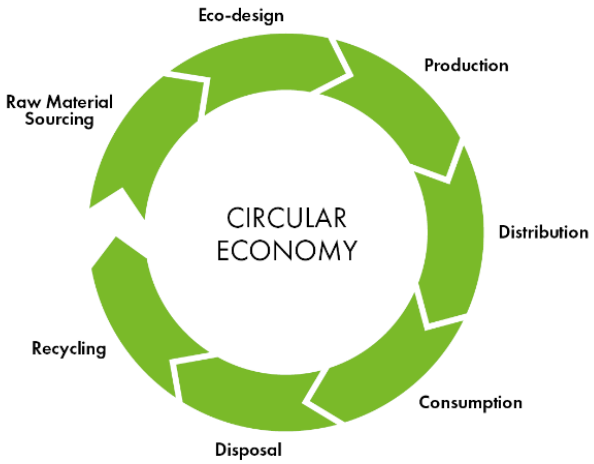

Figure 1: Circular economy

Figure 2: Printing and packaging process chain

In this paper, the sustainability of the printing industry, including sustainable product design, raw materials, industrial forests, ecological and renewable natural fibers, inks, green strategy, solvents and VOC-emissions, recycling, deinking, production optimization, energy use, water footprint, carbon footprint issues have been

evaluated. Suggestions have been made for sustainability in the printing industry.

PRINTING ECOSYSTEM

The main aspects of the ecological sustainability of printing comprise paper production, delivery, printing, renewable and recycled raw material flow, life cycle analysis, low energy consumption, renewable energy use, biomass energy generation, waste of resources, waste separate, recycle and reuse issues (Fig. 3).[16]

Sustainable materials

New products are constantly being added to the list of alternative and recycled materials. In terms of sustainability, the environmental impact of these materials should be considered by printers and suppliers. Whether the materials create waste and danger in terms of the environment and their effect on greenhouse gas emissions should be investigated. If the material contains dangerous or hazardous substances, VOCs or chlorinated substances, it must be properly planned how to properly dispose of waste by-products resulting from its use.[16] The materials needs to be biodegradable, recyclable or made from recyclable materials.

Renewable printing substrates

Renewable means that the product is made from a natural resource that replenishes itself naturally over time. A selection of materials that can be obtained from renewable sources and recycled is an important factor in ensuring the efficient use of resources. Therefore, renewable, recyclable, compostable and biodegradable eco-friendly printing substrates should be preferred for printing and packaging.

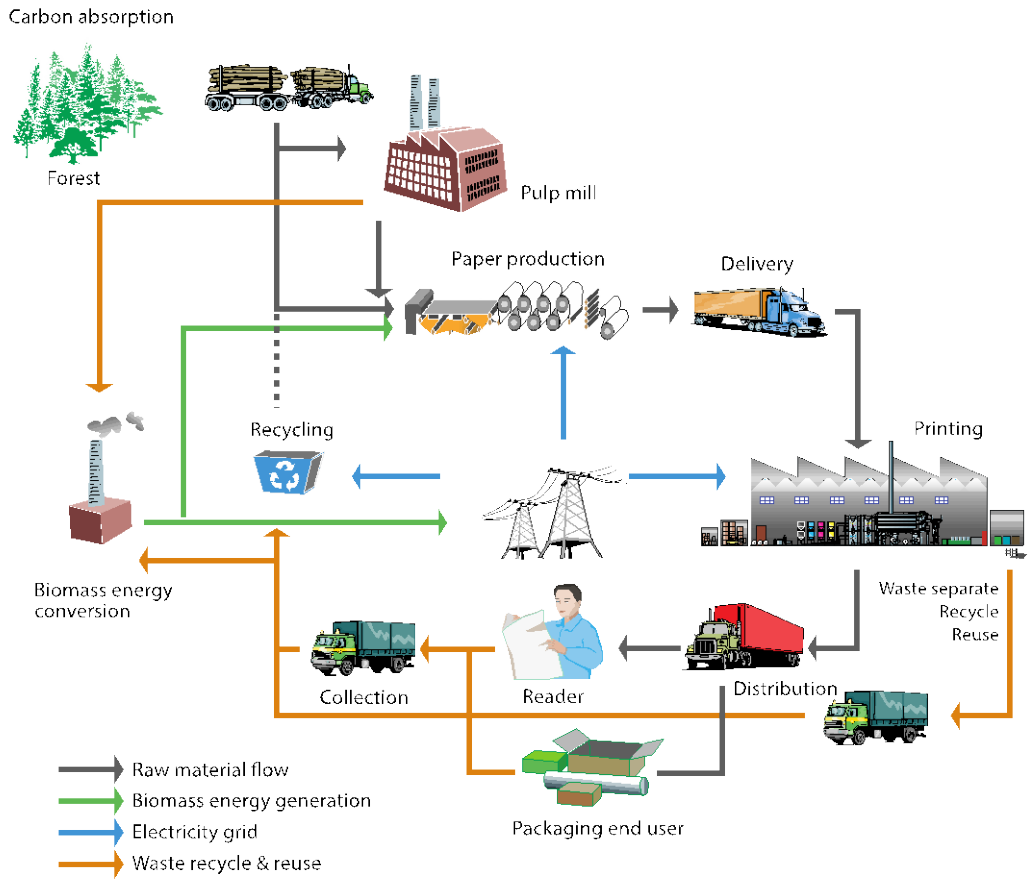

Figure 3: Printing ecosystem

Paper and cardboard are standard substrates based on renewable and recyclable resources. Cellulose, the main raw material of paper and cardboard production, is the main structural component of trees and plants. Cellulose components can be found in both woody (*e.g.*, spruce, pine, eucalyptus, poplar, *etc.*) and non-woody (bamboo, kenaf, abaca, tagasaste, barley straw, wheat straw, *etc.*) biomass.[17] Woody and non-woody fiber sources are the dominant sources

of cellulose for today's global pulp and paper industry. Moreover, biopolymer films are also renewable printing substrates. Biopolymer films are non-toxic and have the main mechanical properties required to preserve the integrity of packaged food. Heat resistant biopolymer films are ideal components of biodegradable food packaging.[18]

Wood fiber resources and industrial forests

The main problems of environmental sustainability lie in the use of natural resources as if they were unlimited in order to meet human needs, interfering with the habitats of other living things, and the irreversible deterioration of the ecological balance by humans. Therefore, renewable wood fibers used in paper and cardboard production must be produced from sustainably managed forests. The goal of industrial forests is to protect and sustain natural forests.

In the world, 92% of paper and cardboard production depends on wood, whether it is soft or hardwood.[4] One of the most important ways to close the supply deficit in wood products is to focus on "industrial plantations". Increasing investments in industrial plantations is important in meeting the need for paper raw materials. Proper forest plantation management can deliver critical environmental, social and economic benefits and increase productivity. The most important reasons for the development of industrial plantations are to meet the need for forests and forest products to avoid dependence on foreign resources, and to supply the needed clean and sustainable energy from bioenergy that causes the least damage to natural ecosystems.[19]

Industrial forests are extremely important for the sustainability of the raw material in paper production too. In recent years, monocultures of fast-growing tree species have been grown up to accelerate cellulose production and reduce costs. These tree species generally consist of fast-growing coniferous and broad-leaved tree species. 40% of forest plantations consist of broad-leaved species, 31% of coniferous species and 29% of these are unspecified species. Pine, *Cunninghamia lanceolata* (Chinese fir), hybrid (*Larix laricina*), red pine, spruce, other coniferous species, non-specific species, some leafy species, such as teak, acacia, poplar and eucalyptus, are tree species that are widely used in industrial plantations around the world.[20] It is noted that priority is given to native species in industrial plantations. The main reason for this lies in the biological, ecological and economic advantages of planting native species.

Among the reasons for the increase and rapid spread of industrial plantations in the world are:

- Meeting the wood-based consumption needs of the increasing world population;
- Protection of declining natural forests;
- Increasing fossil fuel prices day by day;
- Considering global warming, green bioenergy is more environmentally friendly and afforestation areas are used as sink areas due to high carbon absorption;
- Reducing carbon emissions;
- Increasing threat of desertification and erosion;
- Conservation and sustainability of biological diversity.

Certificate of fiber source (PEFC, FSC etc.)

Resource efficiency is of great importance in terms of using the world's limited resources in a sustainable way. Industrial afforestation studies in the world should be carried out in the light of scientific data and considering the ecological balance. Management and custody of forest plantations according to a defined end-use purpose is important.

It is inevitable for the protection and sustainability of forests that products obtained from the forest, such as paper and cardboard, are presented to consumers in accordance with certain standards. The sustainability of renewable tree fiber is granted with certificates like PEFC (Programme for the Endorsement of Forest Certification) and FSC (Forest Stewardship Council). They make sure that forestry is sustainable and that for each tree cut more trees are planted. These certificates are documents stating that the companies that sell or produce forest products are producing in accordance with the determined standards.

PEFC and FSC certificates are proof that paper products are obtained from well-managed forests and controlled sources. With this "Chain of Custody" certificates, raw material can be legally traced. These documents provide assurance that trees are grown specifically for paper production and support responsible forest management by resolving all environmental and social interests.[6] For this reason, printing and packaging companies should also demand that the cartons they use are certified. In addition, they should adopt this

environmental awareness in all processes from pre-production to delivery.

Non-wood plants – alternative natural fibers

The paper industry is primarily dependent on fibrous wood for pulp and paper production. This dependency causes serious environmental challenges, such as declining stocks of fibrous wood, deforestation, greenhouse gas emissions and global warming.[21] To reduce these environmental challenges, other sustainable raw material sources can be considered in paper and pulp production. Alternative non-wood fibers for papermaking may be sustainable under certain conditions. Alternative fibers gain more importance, especially in countries where wood fibers are scarce.[22]

The use of plant-based fibers in paper production has gained importance in terms of real environmental awareness and sustainability. For ecological and sustainable production, plant-based materials have started to take more place in production activities. Natural fibers usually contain cellulose, hemicelluloses, wax or lignin. These fibers are a variety of agricultural or agro-industrial lignocellulosic sources available at a low cost worldwide.[17]

Non-woody plants for the production of cellulosic pulp include wild plants, such as bamboo,[23] different types of cane, such as esparto grass,[5,24] plants with industrial uses, such as abaca, sisal, jute, hemp, ramie, kenaf, flax (Fig. 4),[25] other plants producing high biomass yields (tagasaste, *Leucaena* spp., *etc*.), and can be classified as herbs and legumes.[26-28] These can be considered as alternative fiber sources in papermaking.[29]

Figure 4: Some of the alternative non-wood natural fibers

In general, non-wood raw materials have lower density and a more porous structure. Therefore, in most cases, these non-woody raw materials have lower lignin content, which means less energy and chemical requirements for fiber separation during pulp production. They also have shorter growth cycles than tree species, reach maturity faster, and in many cases, have higher pulp yields.[17,30]

Some other advantages of non-wood raw materials are as follows:

- Non-woody biomass provides an effective alternative to importing wood, paper or cellulosic pulp;
- Non-woody biomass residues increase the added value of agri-food products when used to produce a highly demanded product, such as paper;
- Since the chemical composition of non-woody species is very diverse, papers with different properties can be obtained by selecting and/or mixing these raw materials appropriately compared to traditional wood fiber;
- The use of non-woody fibers as a source in paper production allows more wood resources to be allocated for other woody industrial products.[4,31-33]

Agricultural industrial wastes

Agricultural residues are residues accumulated after the harvest of annual plants, *i.e.* seasonal crops available during summer or autumn. Only about 8% of global paper and board production is based on agricultural wastes. However, it is expected that the percentage of agricultural residues used for paper and cardboard manufacturing will increase gradually and reach at least 10% in the near future.[4]

Cotton stalks, sorghum stalks, corn stalks and flax oil seed, grass seed, rye, oat, agricultural residues, such as barley, rice and wheat straws, are the most important renewable (raw material)

fiber sources used in the paper industry. Concerning the agro-food industry wastes, wastes from sugarcane extraction (sugarcane bagasse), coconut (*Cocos nucifera*) and palm oil (*Elaeis guineensis*) industries can also be used for cellulosic pulp production.[34] Biopolymer films can also be produced from renewable corn and other sugarcane starches.

Sustainable inks and green strategy

Requirements, guidelines, and regulations regarding the prohibition or strict control of hazardous materials are just a few reasons why a printing and packaging manufacturer may develop specific sustainability goals, such as a move to greener materials. The requirements, guidelines and regulations a print and packaging manufacturer must meet in order to achieve their sustainability goals can seem grueling. However, they differentiate the printing and packaging manufacturer's products from their competitors and make them safer and more valuable to consumers, workers and the environment.

Conventional printing inks are mineral oil and solvent-based and cause ever-increasing greenhouse gas emissions. Especially solvent based inks used for flexo, gravure and screen printing, have high concentrations of VOCs. Organic compounds, such as acetone, methanol, cyclohexanone, methyl ethyl ketone and ethanol, used in these printing systems evaporate during the production process or contribute to the photochemical reaction.[35]

More sustainable inks that can reduce the amount of volatile organic and synthetic compounds entering the atmosphere and waste streams could be an important element of the "green" strategy. For this reason, environmentally friendly, non-toxic, VOC-free, renewable and sustainable vegetable oil-based (soybean, linseed oil *etc*.) and water-based inks should be preferred in printing.

The ink content, especially the carrier, makes some inks (water-based, vegetable-based, *etc*.) more sustainable than others (solvent-based, mineral oil-based). Further, the production where green manufacturing inks can be incorporated will help develop an environmentally responsible initiative. This "green strategy" can also create a competitive advantage, especially in the packaging market. Product sales may increase as consumers feel more comfortable knowing that the products they buy are more environmentally friendly. For packaging manufacturers, the use of sustainable ink is especially important in terms of cost. Depending on the ink chosen, cost savings can be achieved in handling, waste disposal, personal protective equipment, permitting, reporting and record keeping.

Print solvents and VOC emissions

VOC emissions other than ink originate from fountain solution additives, lacquers, adhesives, glues, washing-cleaning solvents and other process chemicals used in printing, overprinting and post-press processes. All these volatile solvents, such as printing cylinders and roller cleaners containing ketones, aliphatic and alcohols, blanket washers, isopropyl alcohol (IPA) used in fountain solutions, which are used in the production process, emit steam and cause the release of toxic chemicals into the atmosphere.[35] These VOCs also contribute to the increase in the greenhouse effect and thus to global warming.[36]

In offset printing, the fountain solution contains phosphoric acid, isopropyl alcohol or glycol ethers, together with water. However, many researches have focused on non-ionic surfactants as IPA replacements. This is because of the adverse environmental effects caused by Volatile Organic Compound (VOC) emissions attributed to the evaporation of isopropyl alcohol.[37] When evaluated from an environmental point of view, the ratio of IPA or glycol in the dampening solution should be reduced or IPA-free dampening solution should be used.

Washing and cleaning solutions used in offset printing are mixtures of hydrocarbons, solvent naphthas, oils, surfactants, corrosion inhibitors and other different chemical compounds. However, these compounds cause high VOC emissions. For a safer working environment, new generation water-miscible solvent and surfactant mixtures with lower VOC content should be preferred in cleaning printing cylinders and blankets.

All print houses using inks, coatings, lacquers, chemicals and glues containing VOCs must comply with restrictions to protect health and safety, and prevent environmental pollution. ISO 16759 -- Calculation of the carbon footprint of print media products, and ISO 14001 -- Environmental Management standard are of help to minimize the activities of printing houses that will negatively affect the environment. These international standards provide assurance that any environmental impact is being continually

measured, audited and improved against legislative requirements.

Environmental impact and recovery of solvents

Many raw materials, such as inks, coating hotmelts and cleaners, used in the printing industry contain solvents. Recycling these solvents is important for the economic use of natural resources and sustainability. The tendency to recycle used solvents is increasing day by day. This can be done mainly by means of distillation or filtration. In general, with the use of a good quality solvent recycling system and equipment, about 95 percent of the recycled solvent is reusable and only about 5 percent is decomposed as waste residue.[38]

The recovered solvent can be reused in production processes without any negative side effects. Thus, recycled solvents will help reduce the amount of solvent used by printing companies and the amount of waste produced. In addition to reducing costs and time consumption, businesses will be able to clearly demonstrating green initiatives that are designed to cut down on waste and will be able to market themselves environmentally.

Recycling of paper and cardboard

The transition from linear to circular economy means recycling and reusing existing waste materials to constantly create new products. The fact that a product can be recovered and recycled at the end of its useful life saves resources. Recycling is environmentally friendly, as it contributes to the efficient use of natural resources.[39]

Forests are renewable resources that are key to the production of paper, since the main ingredient of paper is wood pulp (cellulose). Next to their importance for paper, forests are important for the production of other goods, such as timber and firewood, the conservation of biodiversity, the provision of socio-cultural services and carbon storage.[40] One of the positive effects of producing recycled paper and cardboard is the use of less primary fiber, which amounts to less trees cut down. With this choice, less damage is done to the environment, and it can contribute to the protection of natural resources and environmental sustainability.

Paper and cardboard are more sustainable packaging materials, compared to other alternatives, considering their high recycling rate. Paper/cardboard that loses its function can be collected and composted and recycled to obtain a secondary fiber raw material. Then, the recovered fiber can be used for another paper or cardboard production. As a classic example of an efficient raw material cycle, paper can be recycled up to eight times. Recycled paper is also very valuable for consumers. The choice of recycled cardboard in packaging also increases the overall resource efficiency and sustainability.

Another positive effect of recycling is that less energy is consumed. The production of cardboard from recycled fiber saves about 40% more energy than the production of fresh fiber. Recycled fiber meets all requirements in terms of quality and purity.

Separation and processing at source

Recyclable papers are divided into three main groups: mixed paper, household paper and deinking products. In order for these papers and cardboards to be recycled efficiently, they must be separated at their source and using correct separation techniques. Only in this way can high-quality raw materials be created for the papermaking industry.

High quality specialty type papers and other papers used in small quantities in printing houses can be sorted separately with good material flow management and included in the recycling process. In this way, a high level of economic and ecological gains can be achieved continuously in the paper recycling process.

Effects of paper and ink type on deinking

The efficiency of the recycling process is directly related to the paper and ink (solvent) type. According to Li and He, the penetration of ink into the paper surface shows differences between coated and uncoated papers. The average penetration depth in coated papers is between 9.72-16.10 μm. This ratio is 24.07 μm for uncoated paper.[41] This means that the ink that goes deeper in the uncoated paper becomes more difficult to remove from the fibers. This result also shows that the coating layer on coated paper does not allow the ink components to contaminate the fibers. In the study of Imamoğlu *et al.*, during the pulping process with reducing and oxidative bleaches, most of the inks and coloring components in their coated papers were removed from the coating layers, and the resulting pulps exhibited better optical properties than pulps from uncoated papers.[3]

Apart from the fiber structure, the glue, pigment and other additives used in paper production will also directly affect the deinking process as they will determine the penetration and adhesion of the ink to the paper. Therefore, the content of the paper is also important in recycling.

The selection of printing ink is another issue that affects the deinking process. The chemical components of the ink will differ both in terms of environmental impact and removal from the print substrate.

Water, solvent and oil-based ink will affect the deinking process. Nie *et al.* investigated the effect of ink types and printing processes on ink removal from paper. According to the study of X. Nie *et al.* oil-based cold-set and heat-set web-offset inks used in printing processes were easily removed from paper cellulose fibers by flotation.[42] In addition, environmentally friendly vegetable oil-based printing inks, completely free from mineral oil, plasticizers and heavy metals, can be easily removed from printed paper later in the recycling process, thanks to their water solubility. Thus, it can be returned to the materials cycle without any problems.

Water-based flexographic inks used in paper and plastic printing substrates are more environmentally friendly than organic solvent-based inks. However, their use creates difficulties in deinking and recycling processes, as they remain dissolved in water. Conventional deinking technologies, such as flotation processes, do not effectively remove water-based ink particles from the fibers.[43] Other deinking processes are either expensive or have adverse health effects. Under "green" manufacturing and environmental sustainability, deinking of digital print inks is an urgent problem that needs to be solved.[44] During the digital printing process, laser-print toner particles undergo polymerization and oxidation with subsequent formation of peroxide bonds due to exposure to heat, light, and oxygen (air). The oxidation creates a greater polarity at the toner particle surface. The polymerization causes a strong chemical and physical bonding with cellulose fibers and creates larger particle sizes. Both factors cause inefficiency in deinking the paper from toner particles.[42]

One of the most important methods used to remove ink particles from paper fibers is the flotation method.[45] Flicker *et al.* stated that the ink particle diameter should be between 20 and 150 µm for flotation in deinking processes, and the particles over 150 µm were too large to be separated by the flotation process. Besides ink particles with a diameter of less than 20 mm can be removed by washing. However, this leads to water purification problems as it requires high volumes of water.[46] Therefore, liquid electrophotographic inks with smaller particle sizes (1-2 microns) than those of dry toners are also very difficult and costly to remove from paper.[44]

Sustainable product design

Product design refers to the creation of a product (packaging *etc*.) to be printed. Every product design has an environmental impact. Therefore, the designer has to consider the possible environmental effects and make sustainable and correct designs in all of the design stages. In product design, it should be aimed to use resources as long as possible and to minimizing waste and pollution. Products that can be recycled or reused at the end of their lifecycle should be designed.

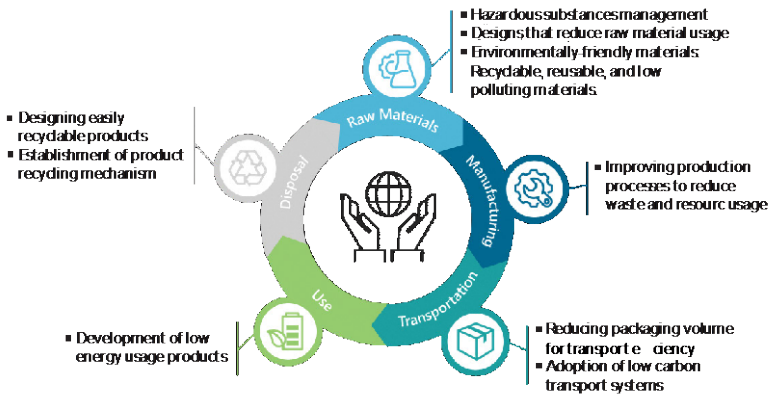

Figure 5: Sustainable product design

Sustainability is becoming increasingly important in product design as consumers and print businesses become more aware of product and production processes' environmental and social impacts (Fig. 5).[47] For this reason, energy efficient and sustainable materials with minimum environmental and carbon footprints should be preferred throughout the supply chain and lifecycle in product designs.

The process of designing a product to be printed involves the selection of graphics, colors and fonts, as well as the printing substrate and printing ink. The density of the solid tone and halftone ink areas on the printed product will make deinking difficult. Therefore, simple designs that require less ink consumption should be preferred.

The design of a printed packaging product is decisive in the recycling process. Packages designed to be effective and safe throughout their lifetime should be able to be efficiently recyclable after use. This re-transformation will become an important criterion in comparing the performance and cost of packaging companies in the common market.[48]

Coating applications, such as overprint lacquer applications, aluminum foil and polymer film, are an important issue to be considered in the packaging design process in terms of recycling. With the separation of cardboard from aluminum and polyethylene, all three of them can have a second chance as raw materials. However, polymer film coatings applied to the surfaces of cardboard packages and disposable products (food carriers, such as paper plates and cups) in order to prevent liquid and heat permeability make the recycling process very difficult. If these synthetic polymer films cannot be recycled, they will harm the environment. Therefore, biodegradable, environmentally friendly biopolymer films should be preferred instead of petroleum-derived films in such coating applications. However, in some cases, the viability of recycling-to-reuse may be an issue if significant additional energy is needed. Resources that cannot be redesigned, reduced, reused or recycled should be disposed of responsibly and, preferably, in a sustainable way.

Production optimization

In order to be able to produce sustainably, resource efficiency and the reduction of CO_2 emissions play a central role. This means that the consumption of raw materials must be reduced and the material cycle must be optimized, while at the same time increasing performance and maximizing energy efficiency.

Today, there is increasing pressure for both processes and products to be environmentally friendly or sustainable.[49] This increased pressure has forced printers to refine their systems, minimize waste and maximize process automation and efficiency. By means of artificial intelligence-controlled, digitized production, by using simulations and algorithms, the print production process will be controlled so that misprints will be minimized, business processes will be accelerated and materials will be used efficiently, resulting in lower raw material consumption.

It has become inevitable to develop different approaches and strategies in the stages from the design of the product to the recovery of the material within the framework of the production function in printing houses. Sustainable production approaches include such issues as reducing waste in the production process, increasing the recyclability of manufactured products and directing the design processes correctly, and developing materials- and energy-saving production processes. The question of how to achieve these goals and what it will cost requires fulfilling the responsibilities required to operate a facility efficiently and economically. For new equipment decisions, comparative performance should be quantified, which reduces material waste, eliminates unnecessary process steps, reduces process waste (air, water, energy), maintenance and noise.[16]

It is necessary to minimize waste by optimizing the use of resources and thereby activating the value of the product in the economy. Thanks to the techniques adopted, standardized production can be made from printing to packaging processes. Global waste can be minimized with print quality, customer satisfaction and process efficiency, thereby achieving successful commercial and environmental sustainability. Production that rests on a streamlined process management and a renewable resource makes printing a highly sustainable and effective ambience. The ISO 12647 series printing industry standard supports efficient operation and less waste with process control and data-driven production.

Energy efficiency

As in every industry, companies in the printing industry need a high amount of energy. This energy is provided from the main sources or by producing their own energy. Environmentally harmful substances are released when energy is produced. There is a direct correlation between CO_2 emissions and the energy generated from fossil fuels. However, not only energy production, but also energy consumption is harmful to the environment. When fossil energy is used in companies, carbon dioxide is released. Too much CO_2 in the air causes global warming. Due to climate change policies, energy costs and greenhouse gas emissions, it has become a necessity for companies to both save money and help the environment.

In general, printing facilities have similar processes. Many processes, including press operation, paper handling, converting, binding, compressed air, humidification control, facility heating and cooling, drying, and emission control, require significant energy. Print houses can help better protect the environment by reducing the energy consumption in these production processes. Old equipment must be constantly replaced with new one, and production must be made with energy efficient technologies. With efficiency analysis, electricity/energy data per product should be calculated. Information on energy consumption should be available and measurable for all machines in the prepress, press, and post-press areas. Printing companies should use the most suitable renewable and clean energy sources, such as sun, wind and water, in order to meet their electricity consumption.[50] They should invest in solar energy technologies and wind energy technologies, such as wind turbines, in order to produce their own energy.

Water footprint

Water is a basic requirement for paper, cardboard, and print production. The water footprint of printing and writing paper is estimated to be between 300 and 2600 m^3/ton (2-13 liters for an A4 sheet).[40] Paper, printing, and packaging manufacturers should try to reduce the use of process water, considering that resources are limited. In addition, the process water can also be recycled through purification, and reused. In this water cycle, climatically neutral biogas can be produced from process wastewater. Neutral biogas obtained from biogas plants and process wastewater reduces the environmental impact of companies. This will be extremely advantageous in terms of environment and sustainability, as well as economically.

Water footprint studies focus on processes based on ISO 14046. An organization's water footprint shows the amount of water it uses directly or indirectly through its impact on water. For this reason, printing companies and paper-cardboard manufacturers should include all activities that directly or indirectly cause water consumption in the inventory work. With these inventory and verification studies, companies can measure their water footprint and reduce it by taking it under control.

The use of recovered paper is thought to be particularly effective in reducing the water footprint of paper. Without recovery, the global average water footprint of paper would be much larger. The study by van Oel *et al*. indicates that, by using recovered paper for the production of paper, the global average water footprint of paper is only 60% of what it would be if no recovered paper would be used at all. This means that estimated 40% global savings are achieved by using recovered paper. In addition, the global water footprint of paper can be reduced by choosing production sites and wood types that are more water-efficient.[40]

Carbon footprint

A carbon footprint of a print product is defined by the amount of fossil carbon dioxide (CO_2) emissions related to all life cycle stages of a finished print production based (Fig. 6).[51] In addition to workflow processes for the printing industry, the carbon footprint of chemicals, such as ink, lacquer, adhesive, dampening solution and cleaning solvent, is extremely important. The majority of the carbon footprint of fiber-based print products is composed of carbon dioxide, methane and nitrous oxide.[52] Reducing emissions and carbon footprints is a good investment both for the company and for a smaller ecological impact. Thus, improvements in climate change and increased environmental efficiency and reduced costs can be benefited from.

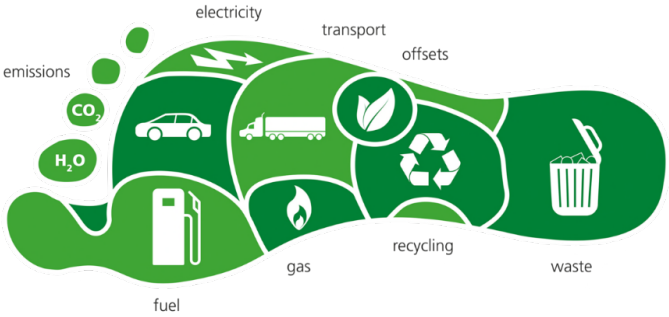

Figure 6: Carbon footprint

Managing the carbon footprint requires printing companies to measure and reduce the carbon emissions of their own production process, as well as upstream and downstream processes if possible.[53] It is in the hands of institutions to measure and control the carbon footprint, product footprint data can be collected from the companies where the products are supplied from, and all activities that cause greenhouse gas effects originating from the institution can be included within the scope of inventory.

There are multiple methods to measure the carbon footprint.[16] ISO 16759:2013 specifies the requirements for quantifying the carbon footprint of those processes, materials and technologies required to produce print media products using any form of printing technology and that are within the user's knowledge and control. Institutional-based carbon footprint can be calculated in accordance with ISO 14064 standard and can be verified by independent organizations. With these collected data, institutional and product carbon footprint can be assessed.

CONCLUSION

This paper has overviewed related research and has made some suggestions for achieving the sustainability of the printing industry, considering the requirements of the sector, what needs to be done in the production process, the efficient use of existing resources, the evaluation of alternatives, recycling, clean energy use and production.

The selection of consumables and printing equipment should be based on their lifetime environmental impact, not just purchase and operating cost.

In the printing and packaging industry, non-fossil based fully renewable printing substrates should be preferred. The raw materials to be used in the production of paper and cardboard must be sourced from sustainably managed industrial forests. In addition, alternative renewable natural fiber sources should be utilized in order to provide raw material diversity. Even agro-food industry wastes can be used for cellulosic pulp production. Thus, forests with commercial and cultural tree species can be protected.

Documentation of the fiber source is essential to ensure that the world's forest products are used correctly and that paper buyers and end users can make informed decisions about the products they purchase. Regardless of the type of fiber used, the fiber source must be verified by reliable scientific and technical data (FSC Certificate) for environmental sustainability.

Environmental inks and recycled papers should be preferred in printing and packaging product designs to be made in line with social responsibility awareness and environmental awareness. Customers should also be guided in this direction. For effective recycling of paper and cardboard, papers and inks that can be deinked more easily should be preferred.

In production processes, environmentally friendly and sustainable inks, lacquers, adhesives, dampening solution (alcohol-free fountain solution *etc*.) and chemicals (cleaning solvent on vegetable oil basis *etc*.) should be used, which can reduce the amount of volatile organic and synthetic compounds released into the atmosphere and the environment. Ink solvents, chemicals, water and other resources used in the manufacturing process must be recycled, so that they can be reused. To that end, printing companies should invest in modern recycling systems.

Various wastes and emissions result from printing and packaging production processes. Print and packaging businesses should control their water use and carbon emission profile to keep their environmental footprint as low as possible. Green production models should be developed considering the effects of chemical

emissions on air, water and soil. Clean engineering studies should be carried out aiming at reducing the carbon footprint, and preventing the production of waste. Manufacturing processes must be rigorously tested to ensure continued reduction in the environmental footprint.

Printing companies should develop a "green strategy" for specific sustainability goals. In this context, the consumption of fossil fuels, such as oil and coal, should be reduced, and investments should be made for the use and production of renewable and clean energy.

Sustainable changes will only happen when printers decide to make their companies more sustainable. For this reason, printing companies should invest in recycling programs, energy-efficient machines, and software and technologies necessary for production with less waste. In enterprises, unnecessary production steps should be avoided, and lean and efficient production techniques based on standardization should be adopted.

Printing houses can contribute to increasing their customers' environmental awareness, involving them in their processes for a joint sustainable success.

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