

# Sustainability through Variable Data Printing

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## Abstract

*As “going green” becomes the expectation rather than the exception, models for proving the environmental compatibility of the entire ecosystem—rather than point devices—will be necessary. In this paper, we explore the ecosystem advantages of variable data printing for sustainability. Sustainability, like security, is more effective when built in from the ground up. Variable data printing (VDP), pre-adapted for use in security printing, is likewise preadapted for utility in sustainable printing. In this paper, we show the preadaptation of VDP toward sustainability, and explore the factors involved in determining the Environmental Return on Investment (E-ROI) of printing.*

## Introduction

A well-supported model for sustainability is needed for the printing business so that consumers of digital media are guided to the best solutions across the gamut of electronic publishing, graphic displays and printed material. Previous models have focused on point comparisons—for example, how many pages must be read on an electronic book reader for it to be as environmentally sustainable as paper? These models generally suffer from the lack of good data on the entire ecosystem aspects of the sustainability. For example, in the paper industry, the relative impact of recycling compared to dedicated forestry is not fully understood. In the electronic book industry, the future costs of recycling—including new levels and types of toxicity—are generally not part of current models.

In this paper, we focus on aspects of the overall ecosystem in which printing or its equivalent (displays and electronic books) occur that can be differentially modeled. This is addressed using a form of sensitivity analysis in which a single, logical component of the ecosystem is removed in order to see which approach—printing, manufacturing, display, electronic book, etc.—provides the best sustainability.

## Variable Data Printing (VDP)

Variable data printing, or VDP, is the use of digital and on-demand technologies to provide customized, individualized and/or otherwise unique print rasters for each item in a series. In one of the simplest forms, VDP is used for mass serialization of for example barcodes, with each barcode having its own unique sequence of characters.

VDP underpins the mass customization of printed materials using digital technologies, as opposed to the analog technologies underpinning offset, gravure, flexo and other traditional printing technologies. With VDP, a run of 2,000 labels, for example, can produce 2,000 unique labels. Offset printing, however, results in 2,000 identical labels.

With VDP, each instance of a package, label, ticket, or other document can contain its own unique identifier. This allows the direct connection of the printed material with on-line content, whether through overt marks such as barcodes [1][2] or covert marks such as digital watermarks [3].

## Preadaptation

Preadaptation is a term from evolutionary biology in which a characteristic, or trait, of a species, is originally selected by the environment because of the survival advantage it provides through one function, but then is later selected for because of the advantage it provides in a distinct function. One obvious preadaptation is feathers, which were originally selected for based on their thermal regulatory properties. This selection, however, led to an unanticipated second functionality in aiding flight.

## VDP and Security Printing

VDP is preadapted to utility in security printing, because security printing also benefits from the attributes of customization, serialization and digital printing. Barcodes used for track and trace benefit from unique serialization, as do other security features such as microtext, graphical alphanumerics, void pantographs and digital watermarks. VDP enables security printing with only a modest (software/graphical artist) increase in cost and effort.

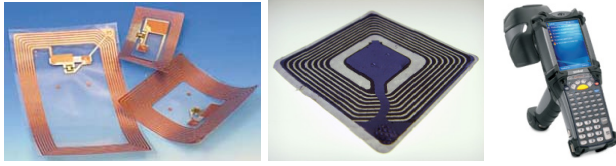
## VDP and Sustainability

VDP is also preadapted to sustainability, inasmuch as the variability offered by different substrates, inks, and printing designs allows printing to be used as a means to change the behavior of sensing, electrical circuits, and other active printing behavior.

How does VDP help sustainability? As with any meaningful topic, there are several ways to cut through the data. One meaningful way is to recognize that there are two broad classes of sustainability:

- (1) Sustainability through Functional Replacement
- (2) Sustainability through Targeting

Sustainability through functional replacement focuses on the ability of VDP to provide the functionality of what are traditionally non-printing capabilities. This includes electric power, through replacement of traditional battery capability [4] or energy scavenging [5][6]; security inks [7]; magnetic inks for MICR reading [8]; and conductive inks to support near field and RFID applications [9][10].



**Figure 1.** Sustainability through Functional Replacement. At the left are printed RFID antennae and the RFID element within. In the center is an RFID sensor surrounded by its printed antenna. The rightmost image is the RFID reader.

Sustainability through Targeting is the environmental value of VDP when it creates a more efficient means of achieving a goal. For example, if targeted advertizing obtained through individually customized magazines results in one sale per 400 customers, while non-customized magazine advertisements results in one sale per 2000 customers, then there is an 80% improvement in targeting these magazines, meaning among other factors a reduction in the amount of materials needed to print the magazine – since on average only 20% as much advertizing will perform the same function as before. Thus, a 100-page magazine with 50 pages of advertisements becomes a 60-page magazine with 10 pages of advertisements, with a 40% reduction in environmental costs.

## The E-ROI Model: Overview

The Environmental Return-On-Investment (E-ROI) model which we introduce is based on the relative cost to the environment of the non-VDP functionality or non-VDP targeting. The example in the previous section shows a 40% increase in total return on investment for printing due to targeted advertizing. A VDP battery that prints for 5% of the cost of a manufactured battery and last 1/10<sup>th</sup> as long would appear to be a 50% improvement on E-ROI. However, other factors (such as the fact, for example, that the batteries it replaces are used, on average, for only 40% of their lifecycle), may improve the overall E-ROI.

Our E-ROI model, therefore, will include, among other factors, the following:

- (1) Environmental cost of materials (Sustainability Cost)
- (2) Relative lifetime
- (3) Effectiveness of replacement
- (4) Recyclability
- (5) Toxicity and future costs of toxicity
- (6) Flow through of value

The last, flow through of value, is particularly important. Technologies which enable later research that may lead to further improvements on E-ROI can be discounted by the future value of the investment, just as technologies that increase future cost to the environment – through toxicity, mutagenicity, etc. – must be penalized accordingly.

## The E-ROI Model

The E-ROI model components are elaborated further here, and then applied to both paper-based and electronic reading. The first component in the E-ROI model, environmental cost of materials, is designated Sustainability Cost (SC), and comprises at minimum the following:

(1) Cost of sourcing the materials. For paper this means the cost of accessing the forest, cutting down and stripping the trees, etc. For electronic devices such as e-readers this includes the cost of mining, sourcing and manufacturing plastics, etc. In either case, recycling will greatly reduce this cost, but that is a separate factor in the overall model.

(2) Cost of undoing the deleterious effects of sourcing. For paper, this means replanting and perhaps re-introduction of species at risk, etc. For electronics manufacturing, this may include the cost of undoing land damage – along with the occasional superfund cleanup – in addition to the replanting.

(3) Cost of land productivity loss. This means the maximum value of the land used for sourcing the materials – in terms of real estate, alternate crops, carbon sinking, etc.

(4) Other greenhouse gas/carbon costs. This includes transportation, re-location of employees, incremental costs of housing, development, etc.

This, SC, is the first factor in the E-ROI. The second factor is *relative lifetime*. Since the cost is inversely proportional to lifetime, then the relative lifetime coefficient,  $k_{RL}$ , is combined with SC as follows:

$$E-ROI = SC / k_{RL}$$

The *effectiveness of replacement* is a direct multiplier, whose value is generally  $\leq 1.0$ . This lowers the relative cost predicted by the model since if the replacement's value is less than the current solution, the current solution's ROI for value add is higher. The coefficient for replacement effectiveness is  $k_E$ , and so this creates the overall model:

$$E-ROI = k_E SC / k_{RL}$$

Next, *recyclability* is considered. Recyclability is at least as complex as the percent of the material that can be recycled multiplied by the relative effectiveness of the recycled material in substitution for the original material. The latter is lower for paper than for metal, as discussed below. However, it is certainly higher for paper than it is for printed circuit boards (PCBs) and many other materials and components in e-readers. The higher the recyclability, the lower the sustainability cost of the product. Thus, the E-ROI model is updated to include the recyclability coefficient,  $k_R$ , as follows:

$$E-ROI = k_E (1 - k_R) SC / k_{RL}$$

Next, the effects of *present and future toxicity* of the product are considered in the toxicity factor, given by the coefficient  $k_T$ . Since higher toxicity increases the relative cost of a product from a sustainability perspective, it updates E-ROI as:

$$E-ROI = k_T k_E (1 - k_R) SC / k_{RL}$$

The *flow through of value* is represented by the coefficient  $k_{FT}$ . Since the overall cost is improved by a larger  $k_{FT}$ , this completes the model as:

$$E\text{-ROI} = k_T k_E (1 - k_R) SC / k_{FT} k_{RL}$$

In order to input values into the final E-ROI model, we consider information provided in references [11]-[13]. In reference [11], it is noted that the recycling of “scrap metal reduces greenhouse gas emissions and uses less energy than making metal from virgin ore. The amount of energy saved using various recycled metals compared to virgin ore is up to: 92 percent for aluminum, 90 percent for copper, and 56 percent for steel.” The reference also notes that metal recycling results in significant impacts on environmental cost of materials, which in our model directly affects  $k_R$ . For example, recycling “one ton of steel conserves 2,500 pounds of iron ore, 1,400 pounds of coal and 120 pounds of limestone. Recycling a ton of aluminum conserves up to 8 tons of bauxite ore and 14 megawatt hours of electricity.” As noted above, basing e-reader recyclability on the scrap metal ignores the lower relative recyclability of most, if not all, other materials and components in the e-readers. However, it will be used herein in order to demonstrate that even under these favorable conditions, the relative sustainability of e-readers is suspect.

In reference [12], it is noted that “The pulp and paper industry is very energy intensive, requires extremely large amounts of water, and often entails the use of toxic chemicals, of which the most problematic are the chlorine compounds used in bleaching pulp to make bright white paper.” Again, maximizing recycling is given as the best path forward. However, for higher grade paper, comprising 27% of the paper manufactured in the US, only 6% of the fiber in the paper is recycled. Recycling reduces energy use by 44%, greenhouse gas production by 37%, waste water by 46%, and solid waste by 49%. In [12], it is also noted that “The number of times paper can be recycled depends upon the quality of the fiber. Poorer quality paper like newsprint has shorter fibers that will break down after 3 or 4 cycles of repulping whereas high-quality printing and writing paper may be able to be repulped up to about 10 times.”

In reference [13], it is noted that 80 percent of U.S. paper mills (115 mills) rely on recycled paper (37% of their material). “Producing recycled paper takes 40% less energy than producing paper from virgin wood pulp. Using recycled scrap paper instead of virgin material saves 7,000 gallons of water per ton of paper produced. Recycled paper production creates 74 percent less air pollution and 35 percent less water pollution than virgin paper production.”

For non-paper products, reference [13] notes: “In 2009, 3.4 million tons of aluminum were generated in the U.S. and 0.69 million tons were recovered. The U.S. recycling rate for aluminum beverage cans reached 58.1% in 2010 – a rate that is more than double that of any other beverage container. [Thus], aluminum cans have 68% recycled content. [Importantly,] 20 recycled cans can be made with the energy needed to produce one can using virgin ore. The pollutants created in producing one ton of aluminum include 3,290 pounds of red mud, 2,900 pounds of carbon dioxide (a greenhouse gas), 81 pounds of air pollutants and 789 pounds of solid wastes.”

Putting together this information, we can obtain absolute and/or relative values of the coefficients for both paper and electronics recycling.

For the relative lifetime coefficient,  $k_{RL}$ , it is not clear that paper is any more or less transitory than an e-reader. Paper can be

preserved indefinitely. Electronic reading material, can be transferred from one device to another. But, e-readers, like laptops, pads and mobile phones, are replaced approximately every two years. A value of 1.0 is assigned to each column in Table 1.

Coefficient	Paper	Electronics
$k_E$	1.0	1.0
$k_{FT}$	1.0	0.8
$k_T$	1.0	1.25
$k_R$	0.44	0.79
$k_{RL}$	1.0	1.0

**Table 1.** Coefficient values for paper and electronics (e.g. e-reader) E-ROI models. See text for details.

Next, effectively of replacement is considered. Since paper has benefits (no power requirements, no boot up time, effective searching) and electronic reading has benefits (faster search, transferability, re-purposability), each is assigned a 1.0 value here.

Based on the recyclability discussion in references [11]-[13], the value  $k_R$  is assigned a value of 0.44 for paper (the mean of 46%, 44%, 37% and 46%) and a value of 0.79 for metal (the mean of 0.92, 0.90 and 0.56).

Toxicity is a concern for both paper and electronics. However, the relative impact of electronics is almost certainly higher, since metals, plastics and toxic agents are involved. A conservative value of 1.0 for paper and 1.25 for electronic systems is given in Table 1.

The last factor is the flow through coefficient,  $k_{FT}$ . Toxicity is the best predictor for the future cost of a product, and so a value of 1.0 for paper and  $1/1.25 = 0.80$  for electronics is given. This is a conservative estimate, since paper has been around for a long time and is less likely to have unanticipated future costs to society.

Combined, these values result in the following estimates for E-ROI for paper and electronics:

$$E\text{-ROI (paper)} = 1.0 * 1.0 * 0.56 * SC / 1.0 * 1.0 = 0.56 SC$$

$$E\text{-ROI (electronics)} = 1.25 * 1.0 * 0.21 * SC / 0.8 * 1.0 = 0.33 SC$$

From this, we can see that the model predicts a better E-ROI – that is, a lower total cost – for electronics compared to paper if:

$$0.33 SC \text{ (electronics)} < 0.56 SC \text{ (paper)}$$

Thus, the e-reader SC costs must be less than 169.7% of the SC costs for printing to provide better sustainability costs. Given the mining, PCB, and other component SC costs, however, it is not clear than e-readers do provide better sustainability. Regardless, this model provides a direct comparison on SC costs alone.

## Future Work and Afterword

Clearly, the sample given above for the E-ROI model is oversimplified. It is intended to illustrate how the different factors in the E-ROI model impact the overall sustainability cost of a product. Future work will focus on providing more in-depth analysis of each of these factors. The present work does illustrate

that an overall environmental cost, based on many factors, can be estimated for variable data printed and electronically read materials.

Interestingly, as this paper was being finalized for the conference, the first author received an email [14] addressing the “creation of a National No-Print Day (NNPD), to be held on October 23, 2012. This nationwide campaign has been designed to encourage, educate, and challenge individuals and companies to commit to one day of ‘no printing’ and to raise awareness of the impact printing has on our planet.”

This email was very timely, and it underscored the need to consider in more depth each of the major factors outlined in the E-ROI model described herein. The email included the following information: “Toshiba claims that our industry has failed ‘to make the link between printing waste and its negative impacts on our landfills, natural resources and the environment.’ ... Our industry has long led the way in utilizing sustainable processes. The primary raw material for printing is paper, which comes from trees, which are a renewable resource—so renewable that today our country has 20 percent more trees than it did on the first Earth Day which was held more than 40 years ago. Printing is the only medium with a one-time carbon footprint—all other media require energy every time they are viewed.” The email also noted that “Electronic devices ... require the mining and refining of dozens of minerals and metals, as well as the use of plastics, hydrocarbon solvents, and other non-renewable resources. Moreover 50–80 percent of electronic waste collected for recycling is shipped overseas and is often unsafely dismantled.”

To address some of the misconceptions involved in understanding the true E-ROI for printing, the Printing Industries of America have provided an informational website [15]. It is obvious from that website, and from the E-ROI model provided in this paper, that factors involved in determining SC are hugely important in estimating the true overall sustainability implications involved in any product. We expect this issue to become increasingly more important as mobile reading devices start to be “recycled” and replaced en masse. Almost certainly, a 20-month replacement lifetime for electronic reading devices is going to cause a reassessment of the “earth friendliness” of products which replace paper. Further reasons for concern regarding e-readers can be gleaned from reference [16], which describe the shockingly low recycling rates ( $\leq 25\%$ ) for electronic devices and their materials (metals, selenium, arsenic, plastics and epoxy resins).

Regardless of the actual environmental costs of printing, it is clear that, as VDP is more ubiquitously adopted, less printing will be performed speculatively. Printing will be more targeted, and as more functionality is added to printing, VDP will be able to

replace more custom manufacturing processes. This will reduce waste, with or without recycling.

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## Author Biography

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